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MICHEL COKE AS A WATER FILTER MEDIA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled MICHEL COKE AS A WATER FILTER MEDIA submitted by ABDUL MAJEED MUSTAPHA in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

ABSTRACT

The object of this investigation was to determine if Michel coke could be used as a filter media in a water treatment plant, and to determine the filtration characteristics of Michel coke.

Two model filters were used, one was a control filter in which the media was filter sand and the other was a test filter which contained Michel coke or coke above fine sand as a composite media. The model filters were operated in parallel at the City of Edmonton water treatment plant. The influent to the filters at the City plant was the water used for the filtration tests. Various flow rates were used for the tests.

The coke and the coarse coke above fine sand are suitable filter media. Both types of media produced an equal or better quality effluent with less head loss than the sand filter.

In order to check the effect of surface area on filtration efficiency the surface area and the surface roughness of the coke grains were reduced by tumbling the coke in ball mills. The tumbled coke was less effective as a filter media. The higher porosity of the coke media explains the smaller head loss; also it was observed that the larger surface area and the surface roughness of the coke grains influenced their ability to remove turbidity more effectively than sand.

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GLOSSARY OF TERMS AND SYMBOLS

Composite Media	- two or more media having different characteristics of size, shape or specific gravity.
Turbidity	- an optical property of water, due to the presence of suspended or colloidal particles, which causes light to be scattered and absorbed rather than transmitted in straight lines through the water.
Michel coke	- is the residue obtained when coking coal is subjected to destructive distillation. It is produced at Michel, British Columbia.
Backwashing	- to reverse the flow of water through the standard rapid sand filter at such a rate of flow as to cause the media to expand and thus remove from the filter accumulated suspended matter which was deposited during the filtering portion of the cycle.
Filter Media	- porous materials used to separate coagulant floc, turbidity and other suspended particles from water by means of filtering action.

GLOSSARY OF TERMS AND SYMBOLS continued

U.S. gpm/sq.ft.	- filtration flow rate in United States gallons per minute per square foot of cross sectional area of the filter media.
Raw water	- untreated water from a natural source of supply.
City Plant	- City of Edmonton water treatment plant.
gr./gal.	- grains per Imperial gallon.
cu.ft./mg.	- cubic feet per million Imperial gallons.
SiO_2	- Silica sand
ppm	- parts per million by weight.
I.D.	- Inside diameter.
Porosity	- the ratio of the total void volume to the total volume of voids plus solid material.

CHAPTER I

INTRODUCTION

1.1 Water filtration may be described as the process by which suspended or colloidal particles are removed from water as it flows through a porous substance. In water supply, clarification by filtration is often a prerequisite to ensure a water quality that is acceptable to the consumer. Sand has been the most universally used material for filtration in water treatment plants, however, in recent years crushed quartz, anthracite coal, and other materials have been advocated as substitutes for sand. Attempts are being made continuously to find new materials which may prove to be more effective than sand as a filter medium.

1.2 There are two types of sand filters in use, the slow sand filter and the rapid sand filter. In slow sand filtration, water flows by gravity downward through the sand at low velocity, usually at rates ranging from 0.032 to 0.160 U.S. gpm per square foot. Rapid sand filters are free-surface type or pressure type. The most widely used type of filter is the free-surface type of rapid sand filter, in which the water flows by gravity downward through the sand, usually at rates ranging from 2 to 3 U.S. gpm per square foot. Pressure filters are enclosed, tight steel cylinders; they are not widely used. Most water treatment plants use rapid sand filtration, although there has been an

enormous amount of research with other types of filter media.

1.3 The principle of filtering from coarse through successively finer grains has been considered in the design of rapid filters. If water is filtered upward through a conventional sand filter it is possible that the sand may start to lift, the porosity of the bed will increase and deposited material will enter into the filtrate. Filtration could proceed in the normal downflow direction if the coarse grains could be maintained at the top, and the fine grains at the bottom, after backwashing (Ives, 1964). This principle is applied in the use of a coarse anthracite layer over fine sand. The media remain in the original configuration because of density grading. Proper selection of media sizes will avoid intermixing. In this type of filter the rate of increase in head loss is less than in the conventional rapid sand filter because the suspended particles are removed throughout the depth of the media. Filters with a composite bed of anthracite and sand are being used successfully in North America (Camp, 1961).

1.4 In the treatment of very turbid waters, coagulation and sedimentation must be used in order to remove the bulk of suspended matter before filtration. If this is not done it may be necessary to backwash the filters too frequently (Dickey, 1961). Coagulation involves a series of chemical and mechanical operations by which coagulants are applied and made effective. Coagulation is a process which facilitates the settling out of impurities; sedimentation is the deposition of the suspended matter. Some other chemical processes which may take place prior to filtration are water softening and disinfection,

however these processes are not filtration aids.

1.5 The physical characteristics of the filter medium have a direct effect on the operation of a filter. It is not yet clearly understood as to which are the predominant removal mechanisms in filtration. Investigators have proposed many different theories, nevertheless the fundamental mechanisms of filtration remain poorly understood. It is generally believed that the filtering action is due to a combination of physical and chemical mechanisms. Craft (1966) states "in all likelihood, the ultimate elucidation of the problem involves not one, but a number of interacting mechanisms."

1.6 There is a continuous attempt to improve filter media and filter equipment. Improved media might enable filters to be operated at higher rates of filtration and thereby reduce the size and cost of filters. It should be noted that filters constitute a major portion of the cost of construction and operation of a water treatment plant.

1.7 The basic criteria for the evaluation of a filter medium are the head loss as the water flows through the filter bed; the rate of change of the head loss as the filter bed becomes clogged with particles removed from suspension; the quality of the effluent; and the backwash characteristics. It is now common practice to measure the quality of filter effluents in terms of turbidity (Camp, 1964). Backwashing is the process by which a rapid filter is cleaned, this cleaning is achieved by a reverse current of clean water which expands the filter bed and scours the filter media, then carries away the accumulated solids to waste.

1.8 The object of this investigation was to determine the filtering characteristics of Michel coke produced from coking coal at Michel, British Columbia; and to determine if Michel coke is suitable as a filter medium in a water treatment plant which uses coagulation, lime-soda softening and sedimentation. A composite media of a layer of coarse Michel coke above a bed of fine sand was also investigated. An attempt was made to determine if the surface roughness and/or the surface area of the Michel coke grains were factors influencing their filtering ability. The performance of Michel coke is evaluated by comparison with filter sand from Eau Claire, Michigan.

1.9 Previous investigation of Michel coke as a filter medium was carried out by Boswell (1966). The basic difference between Boswell's investigation and the present program was in the nature of the suspended particles in the filter influent; Boswell's tests were carried out with non-flocculent materials whereas the present investigation used flocculent materials.

1.10 Two model filters were used in the experiments. One of them was a control filter with sand as the medium and the other was a test filter with crushed Michel coke as the medium. The grain size and grading was the same for both filters. The water used in the test filters was the influent to the filters at the City of Edmonton water treatment plant. Several rates of flow were investigated. Filtration tests were also done using 100 parts per million Kaolin in City tap water as the influent.

1.11 The filter medium in a water treatment plant is used for about 4 to 10 years (Riehl, 1962) before rebuilding may be necessary. In the limited time available it was not possible to determine if Michel coke could be used for several years and still maintain effective filtering characteristics, since it is possible that the grains may become encrusted with deposits of carbonates which can cause the grains to be cemented together and eventually destroy the effectiveness of the filter medium.

CHAPTER II

THEORY OF FILTRATION

2.1 Filtration is one of the most frequently used processes in water treatment (Craft, 1966). However, the design and operation criteria in use today are more art than science; the art was developed primarily through experience in spite of the fact that filtration has been subjected to intense scientific investigations for the past 40 years. Many experiments and studies have been carried out using the most modern techniques of science. Concepts of higher mathematics have been applied to the behaviour of the filter; statistical theory has been applied to predict its performance; electronic digital computers have been used to establish filtration patterns; and radioactive tracers have been used to attempt to trace the path of the suspended particles in the filter (Stanley, 1955). Nevertheless, the fundamental mechanisms of filtration are not clearly understood.

2.2 With regard to the physical aspects of filtration Iwasaki (1937) states that: 1. Filtration is a dynamic process, its action being dependent on depth of and time in, the filter; 2. the removal of suspended particles through the depth of the filter is proportional to the concentration of particles; 3. the constant of the proportionality increases linearly with the amount of clogging, which is time dependent; 4. the material removed from suspension clogs

the filter pores. Stein (1940) modified statement three to read: the constant of proportionality first increases linearly, then decreases non-linearly with the amount of clogging. These statements resulted in numerous complex mathematical formulas and explanations by investigators, who were mainly interested in the mathematical theory of the problem. However, in spite of their efforts an exact mathematical model has not yet been developed. There are also a number of workers who have attempted to establish a physical or chemical explanation for the removal mechanisms of filtration.

2.3 At present investigators do not agree on the means by which a filter medium removes suspended impurities from water. Possible mechanisms for the removal of suspended particles from water by filtration through a porous medium include direct sieving or straining, sedimentation, Brownian movement, flocculation, chance contact caused by the convergence of fluid streamlines, van der Waals effects and electrokinetic effects. (O'Melia and Crapps, 1964). With the exception of van der Waals effects and electrokinetic effects, it can be shown that the other removal mechanisms depend primarily on physical variables, such as grain size, and grain-size distribution of the filter medium, the density of the suspended particles, the rate of filtration, and the temperature of the water.

2.4 Direct sieving or straining is the most obvious removal mechanism of suspended matter from water. Particles which are too large to enter the openings in the filter medium are trapped between the grains. This is mainly a mechanical process of removal, but this does not explain

the fact that particles much smaller than the openings are removed. Hall (1957) states that for straining:

$$P_s \propto \left(\frac{D}{d}\right)$$

where P_s = the probability of removal for a suspended particle.

D = diameter of the suspended particle.

d = diameter of sand particle.

This theory has not gained much support. If removal is a mechanical process, then the size of the particle removed should be independent of its composition. Experiments do not support this theory (O'Melia and Crapps, 1964); it was stated that removal depends on the nature of the suspended particles. Water that has been coagulated generally contains enough residual floc to build up a mat of the floc upon the filter surface. This mat performs some mechanical straining in the filtration process.

2.5 Hazen (1904) proposed a theory which considers each opening in the filter medium as a small sedimentation basin, so that the suspended particles would only have a short distance to settle before reaching a surface. It has been observed that the efficiency of filtration as well as sedimentation decreases with reduction in temperature, although resistance to filtration increases. This theory does not offer any explanation as to why material that has settled out remains out, especially since the velocity increases as the filter bed becomes clogged. It is shown that small floc particles deposit in a filter as a sheath around the sand grains (Camp, 1964), this experimental evidence conflicts with

the sedimentation theory. It should also be noted that this theory does not account for the good removal of watery floc with a density near that of water (Craft, 1966).

2.6 Investigators have suggested that Brownian movement helps to bring suspended particles in contact with the surface of the filter medium. Craft (1966) states that "the effect is appreciable only for particles less than about two microns in diameter and is an insignificant factor in rapid filtration."

2.7 Fair and Geyer (1954) regard floc formation in the filter as a major removal mechanism. As the floc builds up in size it becomes large enough to be retained in the constrictions between the pores. As clogging of the filter occurs, the shearing force may exceed the shearing strength of the floc particles, which are torn apart, thus causing deeper penetration of the filter bed. As temperature decreases the viscosity of the water increases and causes the efficiency of filtration to decrease due to decreased flocculation. O'Melia and Crapps (1964) state that due to the limited detention time in the filter the number of collisions is not high enough for appreciable flocculation.

2.8 Chance contact of suspended particles with each other or with surfaces of the filter medium caused by flow through a constriction has been considered as a removal mechanism (Stein, 1940). Chance contact is brought about mainly by convergence of streamlines at contractions in pore channels and in the vicinity of curved surfaces of the grains. Stein (1940) constructed a filter element which could be mounted on a microscope. The element was transparent lucite so that high speed photomicrographs could be made of the floc in the filter during filtration.

It was observed that floc particles built up a sheath around the simulated grains of a filter. As the thickness of the sheaths increased the velocity and the shearing forces also increased, with the result that fewer particles attached themselves to the sheaths in the upper layers of the filter and were intercepted by the lower layers of the filter. This appears to be a logical mechanism, but it has not been discussed to any great extent in the literature.

2.9 At the molecular level there are a number of attractive and repulsive forces, the most powerful of these forces is known as van der Waals forces. These forces increase in intensity as the particles approach each other. These attractive forces vary inversely as the seventh power of their distance of separation, and thus are of considerable magnitude when the distance approaches the molecular diameter. Mackrle and Mackrle (1961) have developed a model for the sand filtration process based on van der Waals attractive forces and hydrodynamic effects. These authors contend that adhesion between suspended particles and the filter medium is controlled by van der Waals forces. The attractive forces were shown to be unaffected by the nature of the suspended particle, or of the filter media and are dependent almost solely on the density of the material to be filtered from the water. The cohesive forces are additive, so that for large aggregates the force becomes inversely proportional to the cube of the separation distance. Because of the rapid decrease of effect as distance increases, this does not appear to be a dominant removal mechanism. However, it may be the major force which prevents redispersion of the matter that is removed (Mackrle and Mackrle, 1961).

2.10 All solid particles have a charge on their surface when placed in contact with water, for one or more of the following reasons: 1. ionization of molecules at the particle surface 2. unsatisfied charges because of imperfections in the crystal lattice 3. direct chemical reaction with specific ions in the solution, which results in the formation of chemical bonds, and 4. weaker, physical adsorption of ions from solution, as produced by hydrogen bonding or van der Waals forces. At the solid-liquid interface a tightly held layer of ions of opposite charge called the stationary layer and a second, more loosely bound layer of ions of opposite charge called the diffuse layer, are produced. This electrochemical double layer always exerts a repulsive potential between similar particles in an aqueous suspension. The magnitude of this potential and the distance over which it acts are significantly affected by the chemical composition of the aqueous phase. O'Melia and Crapps (1964) give data to show that the filtration process can be dependent upon the surface characteristics of the suspended particles and the filter medium. Cleasby, Williamson and Baumann (1963) state that small ferric floc particles are removed more efficiently than larger particles. This observation supports a theory of electrokinetic effect and is opposite to what would be expected of a purely physical mechanism.

2.11 O'Melia and Crapps (1964) state that significant differences are noted in removal efficiency when comparisons are made between coagulant materials and nonflocculent materials such as diatomaceous earth. Experimental evidence is given to show that the surface properties of ferric floc particles markedly affect their filtrability, and that these

properties depend on the chemical composition of the aqueous phase. These chemical effects in the filtration process are considered to result from interactions between the surfaces of the filter medium and the suspended floc particles; this supports the theory that adsorption is a major removal mechanism in rapid sand filters. It was found that variation in the type of dissolved anion and the pH of the system produced the most significant variations in filtration characteristics. Further development of this idea may lead to fruitful results.

2.12 The foregoing paragraphs give a review of the theory of rapid filtration. The complexity of the problem is obvious, due to large number of variables involved. Among the filter medium variables are grain size, grain shape, grain size distribution and porosity. Some of the applied water variables are concentration of suspended solids, temperature and the rate of filtration. Faber (1960) states "research on the relationship of filter properties to filter performance should be expanded to define the actual function of filtration and reduce its cost to a minimum." Craft (1966) states "the actual set of physical and chemical means by which a rapid sand filter removes particulate matter has been the subject of many investigators but the definitive answer has not been reached."

CHAPTER III

EXPERIMENTAL INVESTIGATION

3.1 Boswell (1966) conducted preliminary investigation of Michel coke as a filter medium. Model filters were set up using coke as the experimental medium and sand as the control medium. A filter influent of constant turbidity was used; City tap water with 100 p.p.m. by weight Kaolin was used as the influent. Several rates of flow were investigated. It was found that the coke sustained less head loss than the silica sand; coke produced a better quality effluent than the silica sand; and the coke required less water for backwashing. Michel coke of varying specific gravities was also prepared by using additives in the process of producing coke. A composite coke bed which consisted of three layers of different specific gravities was also tested at various filtration rates. The composite coke medium removed the turbidity more effectively than the Michel coke medium but sustained higher overall head losses. The composite coke was more efficient than the control sand medium. A coke durability test simulating actual conditions in a water treatment plant was conducted; in this test a coke bed was backwashed continuously for a period which is equivalent to almost ten years of filter use. There was no significant wear of the coke grains.

3.2 The same model filters which were used by Boswell (1966) were used in this investigation. Filtration tests were carried out

using media consisting of sand, Michel coke and a composite media of coarse coke above fine sand.

3.3 The model filters are shown in FIGURES 1 and 2. The filters were made of lucite tubing, nine feet long, approximately 2-3/4 inches I.D. and 0.04 sq. ft. cross-sectional area. The brass orifices on the left side of the filter, numbered M-1 to M-10 inclusive, were 1/4 inch I.D. and extended to the inner face of the tube. Sixty mesh stainless steel screens in the orifices prevented the filter media from entering the tubing. Each open end manometer was connected to the orifices by 1/4 inch flexible tygon tubing which contained a copper T connection at the lowest point of the flexible tubing, so that the manometer and the tubing could be easily flushed. One leg of the T was equipped with a pinch-cock and a short piece of tubing from which samples of water could be taken. The open end manometers were used for head loss measurement. Water overflowed at the top end of the filter into an overflow tray and then to waste. To wash the filter the influent line to orifice A_1 or A_2 was disconnected, FIGURE 3, and this orifice became the overflow point for wash water, which entered the filter at the bottom end at orifice B_1 or B_2, the wash water was regulated by a 1/4 inch needle valve to allow 50 per cent expansion of the original depth of the filter bed.

3.4 The rate of flow was accurately regulated by float-orifice valves, C_1, C_2. The filter effluent flowed through the float-orifice valve into the float tank with a free water surface. The effluent valves E_1 and E_2 were set for the required rate of filtration. As the filter

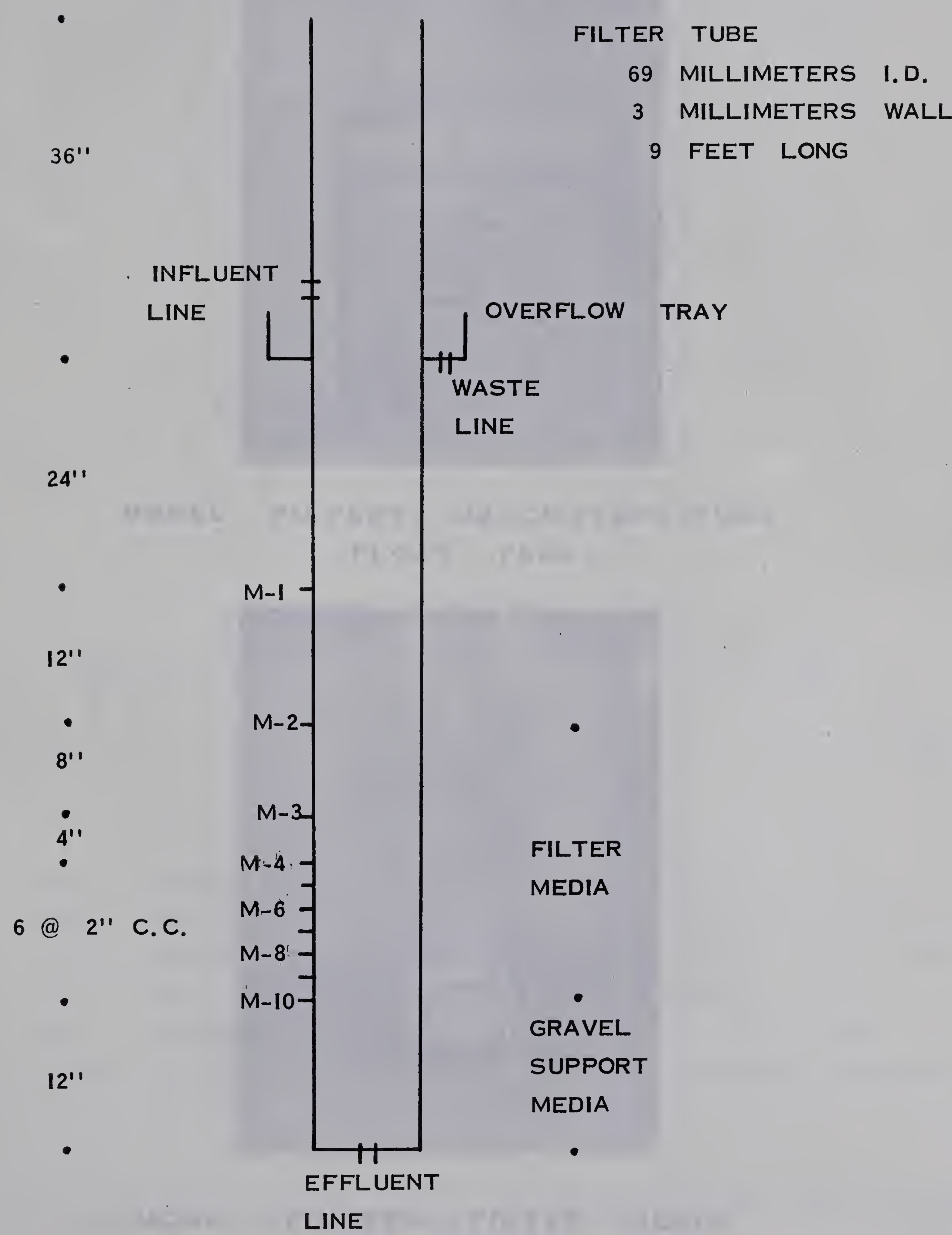
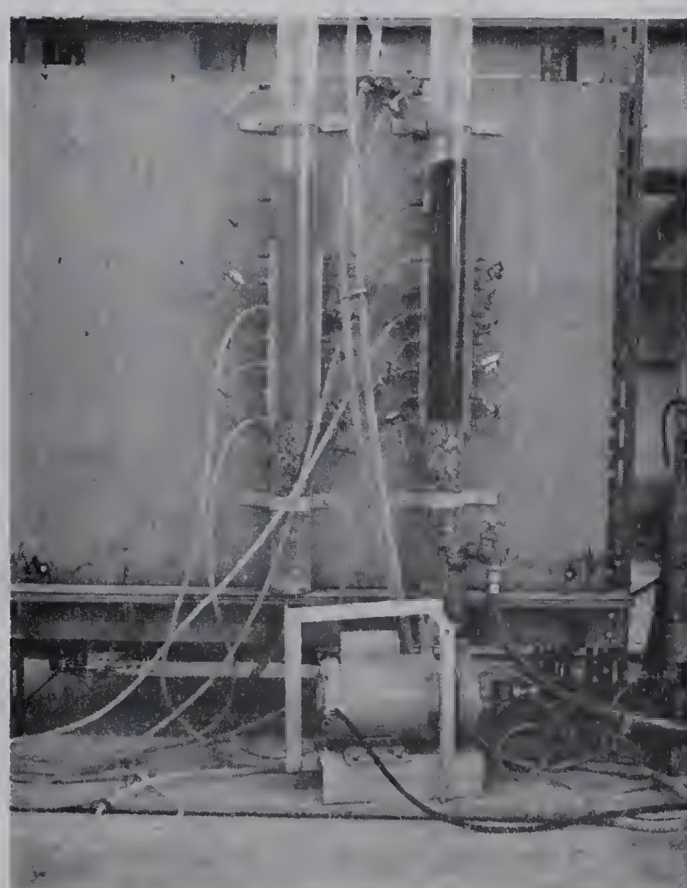


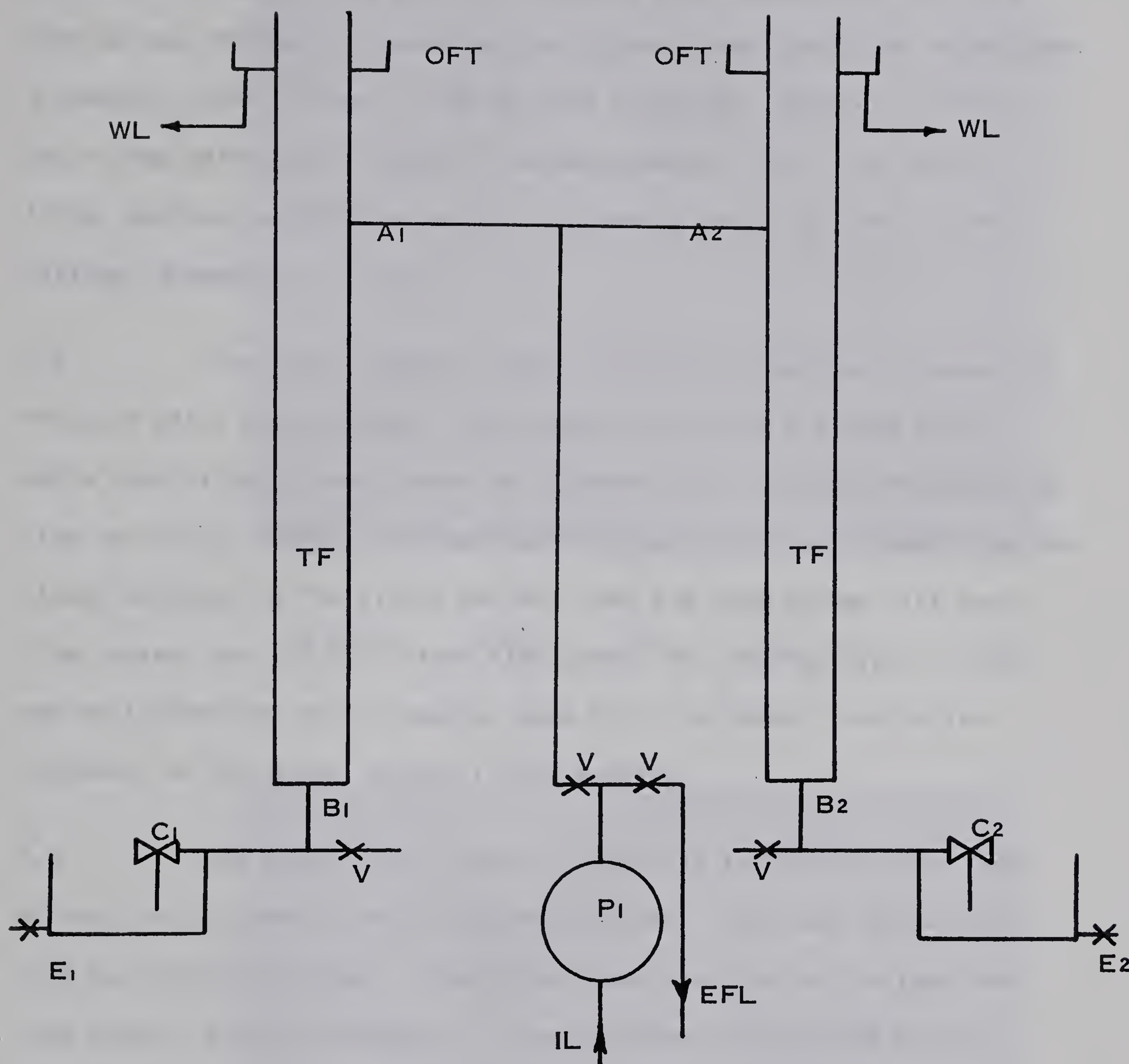
FIGURE I. MODEL FILTER. NOT TO SCALE.

MODEL FILTERS, MANOMETERS, PUMP, FLOAT TANK.



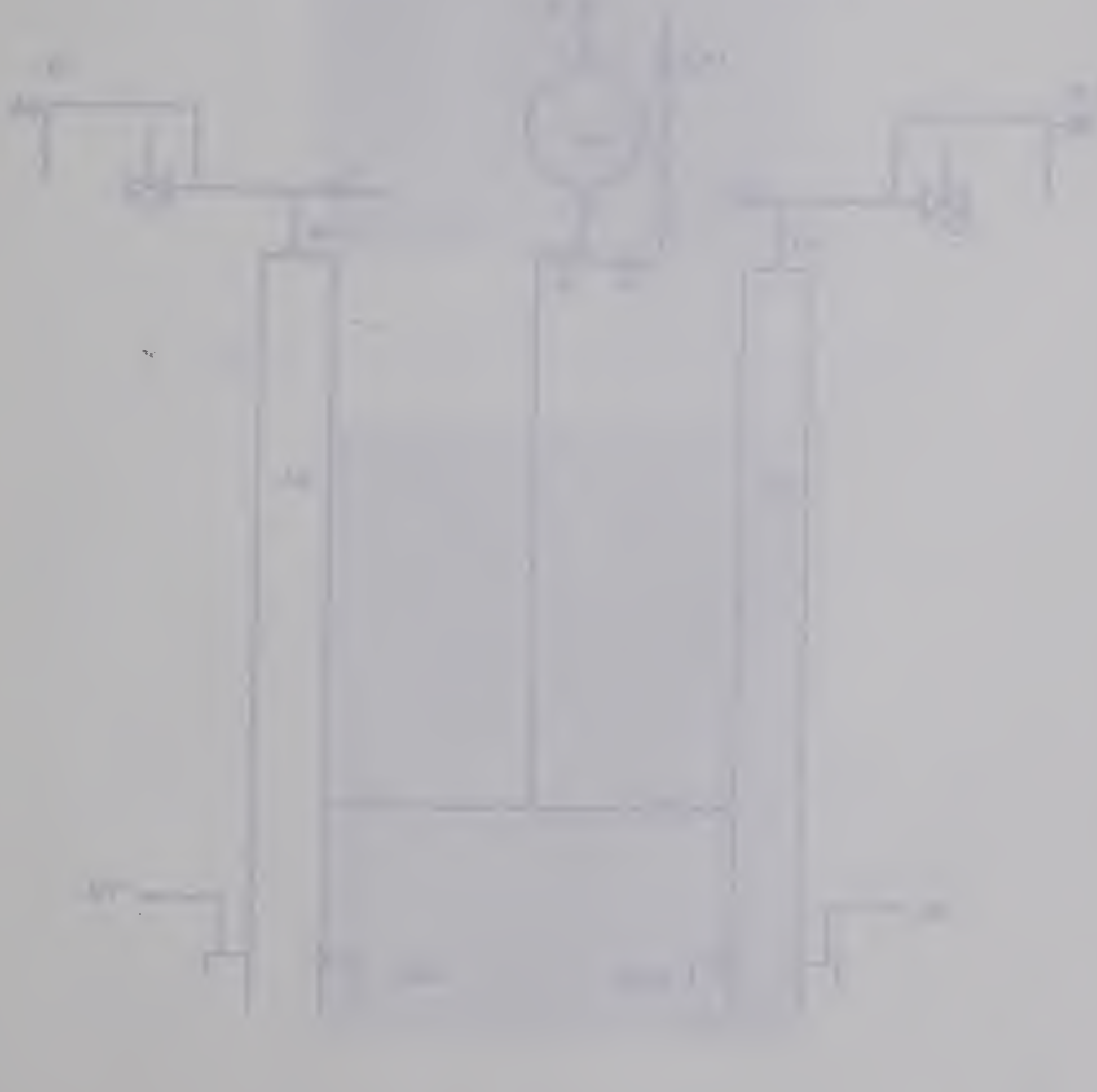
MODEL FILTERS, FILTER MEDIA, AND SUPPORT MEDIA.

FIGURE 2. EXPERIMENTAL APPARATUS.



WL	WASTE LINE	V	VALVE
OFT	OVERFLOW TRAY	E_1, E_2	EFFLUENT VALVES
A_1, A_2	INFLUENT ORIFICES	EFL	EXCESS FLOW LINE
TF	TEST FILTER	P_1	PUMP
CF	CONTROL FILTER	IL	INFLUENT LINE
C_1, C_2	FLOAT ORIFICE VALVES	B_1, B_2	EFFLUENT ORIFICES

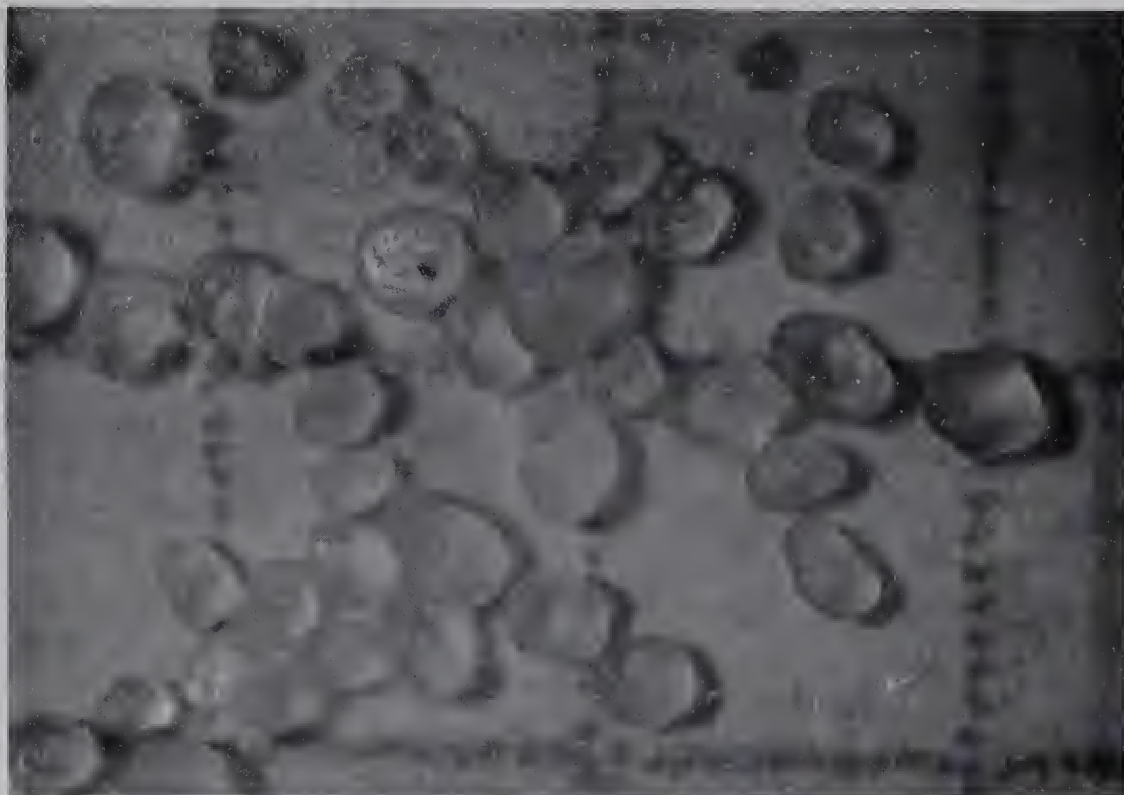
FIGURE 3. FLOW DIAGRAM FOR OPERATION OF TEST FILTERS.



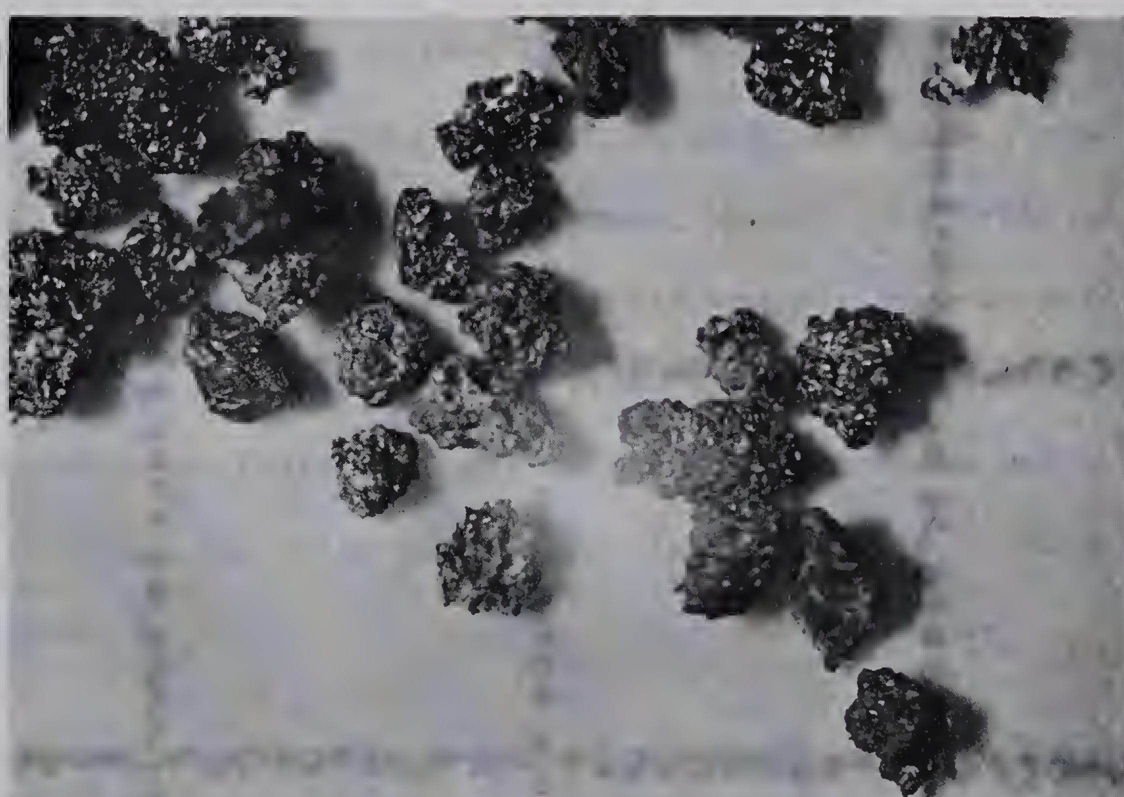
bed became clogged, with particles removed from suspension, the head loss across the bed increased and the rate of flow controller maintained a constant rate of flow. A 500 ml. and a 1000 ml. volumetric flask and a stop watch were used for flow measurements. The flow rate in filter washing was obtained with a stop watch and a 16 liter lucite cylinder graduated in liters.

3.5 The filter gravel supports the filter medium and equalizes the wash water distribution. Each model filter had the same gravel media consisting of four layers of 3 inches each, graded from coarse to fine vertically upward. The maximum size was 15/16 inch diameter agates placed adjacent to the filter outlet, then 5/8 inch agates, 1/4 inch river gravel and 4/8 U.S. sieve size gravel for the top layer. There was no intermixing of the sand or coke with the gravel, and no displacement of the gravel during filter washing.

3.6 The sand in the control filter was the same as that used at the City of Edmonton Water treatment plant. This sand was obtained from Eau Claire, Michigan. The Michel coke was obtained in lump form from Michel, British Columbia. It was crushed and supplied by the Research Council of Alberta. It was sieved to obtain the required grain sizes. TABLE I shows the grain size and grading used for control filter A and test filter B. The Michel coke and control sand grain size and grading are in accordance with the American Water Works Association Standards for Filtering Materials (B100-53). Michel coke is the residue obtained when coking coal is subjected to destructive distillation. It is porous and consists mainly of carbon. The shapes of the sand grains and coke grains are shown in FIGURE 4.



GRAINS FROM SAND MEDIA. 15X.



GRAINS FROM MICHEL COKE MEDIA. 15X.

FIGURE 4. MICROPHOTOGRAPHS OF GRAINS.

TABLE II

GRAIN SIZE AND GRADING FOR MICHEL COKE
AND CONTROL SAND FILTER MEDIA.

FILTERS A AND B.

U.S. Sieve Number Passing	Retained	Percent Passing	Percent Retained
14	16	100	4
16	20	96	26
20	30	70	44
30	40	26	22
40	50	4	4
50	--	0	0

3.7 TABLE II gives a summary of the grain size, the grading and the type of media for the other filters used in this investigation. Filters C and D have composite media of coarse Michel coke above fine sand, and filters E,F, G and H have sand, Michel coke, tumbled Michel coke and anthracite respectively as their media. The media for filter H was prepared by crushing and sieving commercially produced anthracite, the media for filter F was crushed coke, and the media for filter G was crushed coke which was tumbled in a ball mill to reduce the grain roughness.

3.8 In order to alter the roughness of the Michel coke grains 3 ball mills were used, FIGURE 5. The cylinders, 6 inches inside diameter and 8 inches long, were placed on two adjacent bars which were turned by a motor, thus causing the cylinders to turn at 60 revolutions

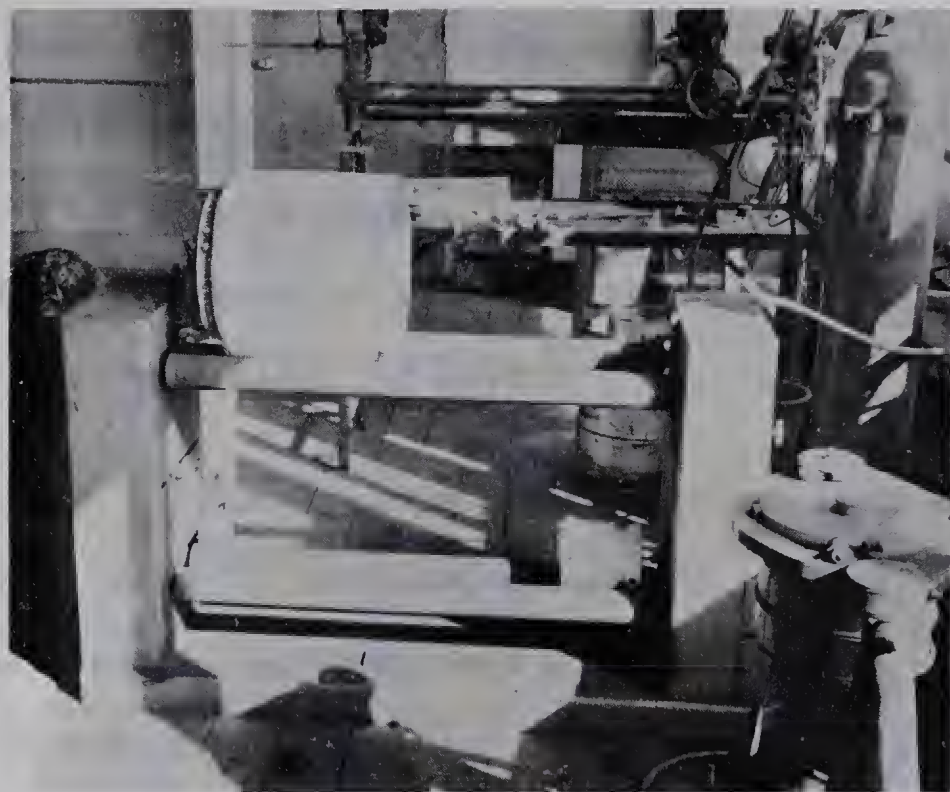
per minute. The cylinders were filled to about one-third with crushed Michel coke of 16/20 U.S. sieve size, together with about one-half the volume of each cylinder of larger grain sizes of Michel coke, the larger sizes ranged between 1/4 inch and number 8 U.S. sieve size. No balls were used in the mills, which were operated continuously for 350 hours. After tumbling the coke was sieved and washed before being used as the media for filter G.

TABLE II

SUMMARY OF GRAIN SIZE, GRADING AND MEDIA FOR TEST FILTERS C, D, E, F, G AND H.

Filter	Media	Media Depth Inches	U.S. Sieve Number 100% Passing	U.S. Sieve Number 100% Retained On
C	Michel Coke	18	8	16
	Sand	8	20	30
D	Michel Coke	8	14	16
	Michel Coke	10	16	20
	Sand	8	20	30
E	Sand	8	20	40
F	Michel Coke	8	20	40
G	Tumbled Michel Coke	8	20	40
H	Anthracite	8	20	40

3.9 Filter tests were between 12 and 30 hours duration. The rates of flow investigated were between 2.0 and 12.0 U.S. gpm per square foot. Head loss, influent turbidity and effluent turbidity readings were taken every hour. Before each filter test, clean city tap water was run



BALLMILL ON PARALLEL BARS.

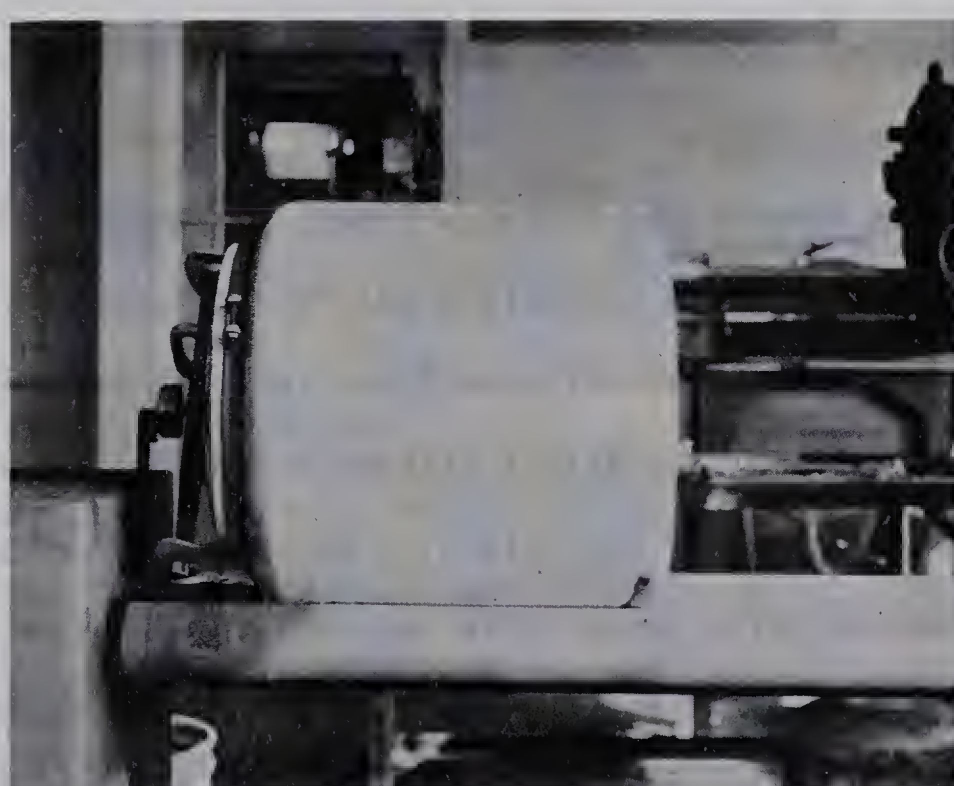


FIGURE 5. BALLMILLS.

through the filters and the flow rate was adjusted to the desired value. At the end of each filter test the filter was backwashed with tap water until the wash effluent was clear. The wash influent valve was closed gradually over 1 1/2 minutes to maintain uniform depth and grading of the filter media. At the end of each run the orifices, manometers and tubing were flushed with clean tap water.

3.10 In the City of Edmonton water treatment plant North Saskatchewan River water is softened, coagulated, settled, sterilized and filtered before distribution. Cold process lime-soda softening is used from October to April and lime softening for the summer months. Filter alum and small quantities of aluminum silicate are used as coagulants to promote clarification by settling. Sterilization is accomplished with chlorine and ammonia. Raw water, with all chemicals except chlorine enters the first flocculator sections through the influent flumes. These flumes are so designed that a rapid mix is obtained by means of the turbulent flow of the water passing through. In the flocculator, mechanically driven paddles impart a gentle barrel-roll motion to the water passing through, causing the small floc particles, which were previously formed by chemical additions, to coalesce into large sized, tough particles, which readily settle out into the first clarifier sections, mechanically sweeping out color and turbidity with them. The clarifier sections are equipped with rakes, which automatically gather this settled floc into sumps from where it is discharged into the river. The settled water from the first clarifiers is taken off over a weir and enters the first carbonation section where any excess lime that has not been used up in the softening reaction is precipitated

with carbon dioxide gas as calcium carbonate. This second floc or precipitate is then settled out in the second flocculator-clarifier sections. The settled water is again taken off over a weir and enters the second carbonation section where the small amount (35 to 40 parts per million) of calcium carbonate that remains in solution following the softening reactions is stabilized with carbon dioxide gas. The water then flows through the final settling basins where chlorine dioxide and chlorine are added, and then to the rapid sand filters at the City plant and the model filters used in the experimental tests with filters A, B, C and D. The water was pumped to the filters by pump P_1 (FIGURE 3). In the tests at the City plant filters B, C and D were tested in parallel with control filter A.

3.11 For tests with filters E, F, G and H the influent was 100 parts per million Kaolin clay in City tap water. The suspension was prepared by adding 20.45 grams Kaolin to 45 Imperial gallons of tap water. It was mixed in a plastic barrel in which a small submersible pump was placed to keep the turbidity in suspension. The water was pumped to the test filters by pump P_1 (FIGURE 3). The excess flow was returned to the feed barrel.

3.12 Ling (1955) states, "Turbidity expressed as parts per million (ppm) has been universally used to indicate the cloudiness of water in the water filtration field." There are several kinds of turbidity - measuring devices which have been used in water treatment plants such as Jackson-Candle meter, Baylis meter, Hellige meter and many other types. In the tests at the City plant the Hellige

turbidimeter (Serial No. 313) was used. This instrument is particularly efficient in measuring low turbidity ranges, even to fractions of 1 part per million silica. Turbidities as low as 0.05 ppm can readily be detected. By utilizing the various tubes and light filters furnished with the instrument, the complete turbidity scale from 0 to 150 ppm SiO_2 can be accurately measured. There are individual calibration graphs for the following turbidity ranges 0-5, 0-15, 0-50 and 0-150 p.p.m. SiO_2. Higher values are determined by diluting the sample with distilled water. Measurements with the Hellige turbidimeter utilize the unique principle based on the Tyndall effect. A beam of light passing upward through the turbid sample is compared to light which is scattered upward by the suspended particles when they are illuminated from the side.

3.13 In the tests using Kaolin turbidity the Bausch and Lomb Spectronic 20 Spectrophotometer was used for turbidity analysis. With this instrument the concentration of turbidity in the sample is related to the proportion of light that is transmitted through the sample. FIGURE 10 is a calibration curve (Boswell, 1966) which shows concentration vs logarithm per cent light transmission.

3.14 A 1000 ml. graduated cylinder was used to determine the porosity of the filter media. The porosity is the ratio of the total void volume to the total volume of the voids plus solid material. The volume of the voids and the solids was determined. The volume of the solids was determined knowing the dry weight and the specific gravity.

3.15 Specific surface area was determined by the technical staff of the Department of Chemical Engineering, University of Alberta. The method of Nitrogen adsorption was used. The apparatus used was the automatic Carlo Erba Sorptomat. A measured volume of Nitrogen was introduced into a sample and the amount adsorbed was measured. The amount of Nitrogen adsorbed in a mono-molecular layer was determined. This was used to calculate the surface area.

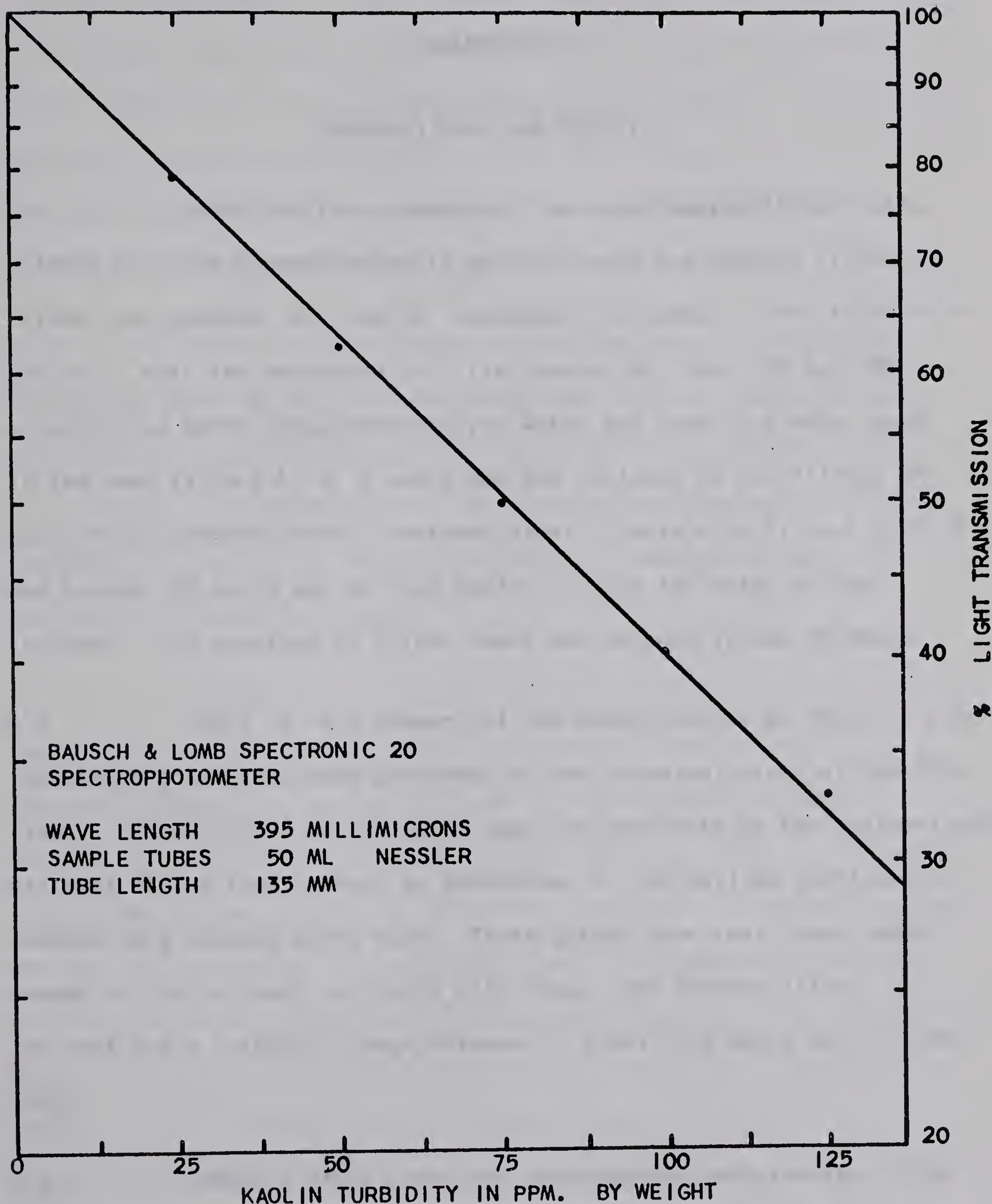


FIGURE 6. SPECTROPHOTOMETER CALIBRATION.

[AFTER BOSWELL]

CHAPTER IV

OBSERVED DATA AND RESULTS

4.1 TABLE III is a summary of the experimental filter tests. Filters B, C and D were tested in parallel with the control filter A. Filter runs labeled 1A and 1B represent run number 1 with filters A and B . With the exception of filter tests 14A, 14B, 15A and 15B, in which raw North Saskatchewan River water was used, the water used in the test filters A, B, C and D was the influent to the filters of the City of Edmonton water treatment plant. Tests with filters E, F, G and H used 100 parts per million Kaolin in City tap water as the influent. The duration of filter tests was between 12 and 30 hours.

4.2 TABLE IV is a summary of the water quality at the City plant. The chemical analyses were performed by the technical staff at the City plant. FIGURES 23 to 36 inclusive show the turbidity of the influent and effluent of the test filters as determined by the Hellige turbidimeter, samples were checked every hour. These graphs show that there was a change in the influent turbidity with time. The treated filter influent had a turbidity range between 2.75 and 15.0 parts per million SiO_2.

4.3 TABLES V AND VI give the experimental data for the filter runs 13A and 13B respectively. Head loss and turbidity readings were

taken every hour for the first 12 hours then readings were taken every 2 hours for the next 18 hours. The total head loss for the sand filter A increased from 0.65 to 3.39 feet and the total head loss for the Michel coke filter B increased from 0.38 to 2.06 feet. The effluent for both filters had zero turbidity readings throughout the run. With the exception of the duration of the filter runs these tables are typical of the tests with filters A, B, C and D.

4.4 TABLE VII is a summary of the data and results of the filtration tests at the City plant with filters A, B, C and D. The initial and final head loss and turbidity readings are given. TABLE VIII is a summary of the data and results of the filtration tests with 100 parts per million Kaolin in City tap water as the influent, the tests were with filters E,F, G and H.

4.5 FIGURES 7 to 11 inclusive show the total head loss in feet vs time in hours for filters A and B which were operated in parallel between the rates of 2.4 and 12.0 U.S. gpm/sq.ft. The rate of increase of head loss was greater for sand filter A than for Michel coke filter B at all rates of filtration. The total head loss was greater for filter A than for filter B in each case. FIGURES 23 to 26 inclusive give the influent and effluent turbidity, in parts per million SiO_2, vs time in hours for filters A and B . At 2.4 U.S. gpm/sq.ft. the effluent of both filters had zero turbidity. At higher rates of filtration filter B had an effluent of lower turbidity.

4.6 FIGURES 19 and 20 show head loss vs time for filter runs 14A, 14B, 15A and 15B, in which the filter influent was raw North Saskatchewan River water. Michel coke had a lower head loss than the sand. FIGURES 35 and 36 show the influent and effluent turbidity vs time for the same tests. The effluent for both filters had a high turbidity reading, which ranged between 4.0 and 11.0 ppm SiO_2.

4.7 FIGURES 11 to 18 inclusive show head loss vs time for the tests with filters A, C and D. Filters C and D were each operated in parallel with filter A at filtration rates between 3.0 and 12.0 U.S. gpm/ sq.ft. In each case Filter A had a higher total head loss than the filters of the composite bed of Michel coke and sand, that is filters C and D. FIGURES 27 to 34 inclusive show the influent and effluent turbidity vs time for filters A, C and D. At a filtration rate of 3.0 U.S. gpm/sq.ft. the effluent for filters A and C had zero turbidity throughout the filter test. The effluent for filter D had zero turbidity up to a filtration rate of 5.0 U.S. gpm/sq.ft. At the higher rates of filtration filters C and D produced an effluent which had lower turbidity than filter A.

4.8 TABLES IX, X and XI give summaries of the increase in head loss between different orifices for the tests with filters A, B, C and D. For the tests with filters A and B which used the treated City plant influent the head loss was confined to the upper layers of the filters, there was negligible head loss between M-4 and M-10. For filter runs 14A, 14B, 15A and 15B which were conducted with raw North Saskatchewan River water the head loss was distributed throughout

the filter beds; the turbidity of the effluent was high for both filters. For tests with filters C and D the head loss was distributed throughout the filter bed; the upper layers of coarse Michel coke removed the larger turbidity particles and the lower layers of fine sand acted as a polisher to remove the fine turbidity particles.

4.9 The test filters A and B were in use for approximately 3 weeks before the media of filter B was replaced. At the end of all the filtration tests with filter B the total head loss for various filtration rates was obtained by using clean City tap water as the influent. TABLE XII is a summary of the initial head loss before and after use in the filtration tests with filters A and B. There was no difference in the initial and final head losses, therefore it is likely that the media grains did not become encrusted with carbonates during the testing program.

4.10 FIGURES 21 and 22 show head loss vs time for tests with filters E,F, G and H. The sand filter E had the highest head loss and the anthracite filter H had the next highest head loss. At the start of the filtration test the rough Michel coke filter F had higher head loss than the tumbled Michel coke filter G, after about 8 hours filtration at 2.0 U.S. gpm/sq.ft. the filter G had a higher head loss than filter F. A similar trend was noticed after about 6 hours filtration at 4.0 U.S. gpm/sq.ft. This change might be due to the lower porosity of filter G. Both filters F and G had less head loss than filters E and H. FIGURES 37 and 38 show per cent light transmission vs time in hours for filters E, F, G and H. The rough Michel coke

filter F produced the best quality effluent and sand filter E the worst, with the effluents of filter G and H in the intermediate range between that of E and F.

4.11 TABLE XIII is a summary of the specific surface area, porosity and filtration results for the media used in filters E, F and G. The rough coke had the highest porosity and specific surface area, the lowest head loss and produced the best quality effluent. The tumbled coke had lower porosity, specific surface area, higher head loss and produced a poorer quality effluent. The filter sand had the lowest values for the porosity, specific surface area and quality effluent, with the highest head loss.

TABLE III

SUMMARY OF EXPERIMENTAL TESTS

Run	Media	Media Depth Inches	Depth of Water Above Media (feet)	Rate U.S. gpm/ sq.ft.	Filter Influent	Duration - hours
1A	Sand	26	5.83	2.4	City Plant	16
1B	Michel Coke	26	5.83	2.4	City Plant	16
2A	Sand	26	5.83	5.0	City Plant	12
2B	Michel Coke	26	5.83	5.0	City Plant	12
3A	Sand	26	5.83	10.0	City Plant	12
3B	Michel Coke	26	5.83	10.0	City Plant	12
4A	Sand	26	5.83	12.0	City Plant	12
4B	Michel Coke	26	5.83	12.0	City Plant	12
5A	Sand	26	5.83	3.0	City Plant	12
5C	8/16[1] Michel Coke	18	5.83	3.0	City Plant	12
	20/30 Sand	8				
6A	Sand	26	5.83	5.0	City Plant	12

1. U.S. Sieve numbers.

TABLE III continued

Run	Media	Media Depth Inches	Depth of Water Above Media (feet)	Rate U.S. gpm/ sq.ft.	Filter Influent	Duration - hours
6C	8/16 Michel Coke	18	5.83	5.0	City Plant	12
	20/30 Sand	8				
7A	Sand	26	5.83	8.25	City Plant	12
7C	8/16 Michel Coke	18	5.83	8.25	City Plant	12
	20/30 Sand	8				
8A	Sand	26	5.83	12.0	City Plant	12
8C	8/16 Michel Coke	18	5.83	12.0	City Plant	12
	20/30 Sand	8				
9A	Sand	26	5.83	4.0	City Plant	12
9D	14/16 Michel Coke	8	5.83	4.0	City Plant	12
	16/20 Michel Coke	10				
	20/30 Sand	8				
10A	Sand	26	5.83	5.0	City Plant	12

TABLE III continued

Run	Media	Media Depth Inches	Depth of Water Above Media (feet)	Rate U.S. gpm/ sq.ft.	Filter Influent	Duration - hours
10D	14/16 Michel Coke	8	5.83	5.0	City Plant	12
	16/20 Michel Coke	10				
	20/30 Sand	8				
11A	Sand	26	5.83	8.25	City Plant	12
11D	14/16 Michel Coke	8	5.83	8.25	City Plant	12
	16/20 Michel Coke	10				
	20/30 Sand	8				
12A	Sand	26	5.83	12.0	City Plant	12
12D	14/16 Michel Coke	8	5.83	12.0	City Plant	12
	16/20 Michel Coke	10				
	20/30 Sand	8				
13A	Sand	26	5.83	2.4	City Plant	30
13B	Michel Coke	26	5.83	2.4	City Plant	30
14A	Sand	26	5.83	2.4	Raw Water	12

TABLE III continued

Run	Media	Media Depth Inches	Depth of Water Above Media (feet)	Rate U.S. gpm/ sq.ft.	Filter Influent	Duration - hours
14B	Michel Coke	26	5.83	2.4	Raw Water	12
15A	Sand	26	5.83	5.0	Raw Water	12
15B	Michel Coke	26	5.83	5.0	Raw Water	12
16E	20/40 Sand	8	7.33	2.0	100 ppm Kaolin	12
16F	20/40 Michel Coke	8	7.33	2.0	100 ppm Kaolin	12
16G	20/40 Tumbled Michel Coke	8	7.33	2.0	100 ppm Kaolin	12
16H	20/40 Anthracite	8	7.33	2.0	100 ppm Kaolin	12
17E	20/40 Sand	8	7.33	4.0	100 ppm Kaolin	12
17F	20/40 Michel Coke	8	7.33	4.0	100 ppm Kaolin	12
17G	20/40 Tumbled Michel Coke	8	7.33	4.0	100 ppm Kaolin	12
17H	20/40 Anthracite	8	7.33	4.0	100 ppm Kaolin	12

TABLE IV

WATER QUALITY AT CITY PLANT

Run	Temp. °F	Raw Turbidity ppm SiO_2	Treated pH	Lime gr/gal	Alum gr/gal	Natural gas cu. ft/mg.	TREATED Hardness Total	Hardness Non. Carb.	Alkalinity MeO	Alkalinity Pp	Ca	Mg
1A & B	55-60	50-75	9.5	102.3	14.7	1.56	56	26	30	10	38	18
2A & B	58-60	35-80	9.4	99.6	9.2	0.93	60	26	34	14	40	20
3A & B	55-60	20-30	9.2	91.9	7.7	1.68	60	24	36	8	38	22
4A & B	55-60	25-30	9.3	94.6	7.8	1.22	58	28	30	10	38	20
5A & C	55-60	10-15	9.0	99.3	7.8	1.36	68	36	32	12	52	16
6A & C	55-58	Over 100	9.5	116.0	30.2	1.65	60	24	36	15	50	10
7A & C	56-58	40-75	9.0	112.5	6.0	1.44	62	22	40	14	48	14
8A & C	57-58	75-90	9.4	109.2	15.1	1.33	66	26	40	18	50	16
9A & D	55-58	7-11	9.0	95.3	7.8	1.29	64	32	32	12	44	20
10A & D	60-65	10-15	9.2	93.8	7.8	1.32	70	32	38	14	46	24
11A & D	60-64	8-13	8.8	100.4	8.3	1.33	66	32	34	6	46	20
12A & D	58-63	8-12	9.0	101.1	8.0	1.29	64	30	34	10	40	24
13A & B	55-60	35-40	9.7	100.9	11.0	0.88	60	28	32	12	40	20

TABLE V

EXPERIMENTAL DATA FROM RUN 13A

SAND FILTER 2.4 U.S. GPM/SQ.FT.

Hours From Start	Head Loss - Feet Orifice Number M - 4	M - 10	Turbidity ppm SiO_2 Influent	Effluent
0	0.40	0.65	7.20	0.00
1	0.43	0.69	7.20	0.00
2	0.48	0.74	7.20	0.00
3	0.54	0.80	5.40	0.00
4	0.60	0.87	5.40	0.00
5	0.67	0.94	7.20	0.00
6	0.75	1.03	7.20	0.00
7	0.86	1.14	5.40	0.00
8	0.97	1.25	5.00	0.00
9	1.09	1.37	5.00	0.00
10	1.18	1.46	5.00	0.00
11	1.29	1.57	5.40	0.00
12	1.42	1.71	7.20	0.00
14	1.60	1.89	7.20	0.00
16	1.78	2.07	7.20	0.00
18	1.93	2.22	5.40	0.00
20	2.06	2.35	5.40	0.00
22	2.22	2.51	5.40	0.00
24	2.40	2.69	5.40	0.00

TABLE V continued

Hours From Start	SAND FILTER Head Loss - Feet Orifice Number M - 4	M - 10	2.4 U.S. GPM/SQ.FT. Turbidity ppm SiO_2 Influent	Effluent
26	2.62	2.91	5.40	0.00
28	2.85	3.14	5.40	0.00
30	3.09	3.39	5.40	0.00

TABLE VI

EXPERIMENTAL DATA FROM RUN 13B

MICHEL COKE FILTER 2.4 U.S. GPM/SQ.FT.

Hours From Start	Head Loss - Feet Orifice Number M - 4	M - 10	Turbidity ppm SiO_2 Influent	Effluent
0	0.25	0.38	7.20	0.00
1	0.28	0.41	7.20	0.00
2	0.31	0.44	7.20	0.00
3	0.34	0.48	5.40	0.00
4	0.38	0.52	5.40	0.00
5	0.42	0.57	7.20	0.00
6	0.48	0.63	7.20	0.00
7	0.52	0.67	5.40	0.00
8	0.57	0.72	5.00	0.00
9	0.61	0.76	5.00	0.00
10	0.67	0.83	5.00	0.00
11	0.74	0.90	5.40	0.00
12	0.80	0.96	7.20	0.00
14	0.89	1.05	7.20	0.00
16	0.96	1.12	7.20	0.00
18	1.03	1.19	5.40	0.00
20	1.12	1.28	5.40	0.00
22	1.26	1.42	5.40	0.00
24	1.37	1.53	5.40	0.00

TABLE VI continued

MICHEL COKE FILTER 2.4 U.S. GPM/SQ.FT.

Hours From Start	Head Loss - Feet Orifice Number M - 4	M - 10	Turbidity ppm SiO_2 Influent	Effluent
26	1.53	1.69	5.40	0.00
28	1.71	1.87	5.40	0.00
30	1.89	2.06	5.40	0.00

TABLE VII

SUMMARY OF FILTRATION DATA AND RESULTS AT THE CITY PLANT

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss (feet)			Effluent Turbidity ppm SiO_2	
			Initial	Final	Increase	Initial	Final
1A	2.4	16	0.65	2.14	1.49	0.25	0.00
1B	2.4	16	0.38	1.23	0.85	0.25	0.00
2A	5.0	12	1.55	4.32	2.77	0.25	0.25
2B	5.0	12	0.57	1.95	1.38	0.00	0.00
3A	10.0	12	2.75	5.62	2.87	0.65	1.25
3B	10.0	12	1.10	3.10	2.00	0.25	0.25
4A	12.0	12	3.30	6.24	2.94	0.25	0.90
4B	12.0	12	1.42	4.17	2.75	0.00	0.25
5A	3.0	12	0.83	2.19	1.36	0.00	0.00
5C	3.0	12	0.32	0.72	0.40	0.00	0.00
6A	5.0	12	1.55	3.97	2.42	0.90	0.20
6C	5.0	12	0.58	1.47	0.89	0.50	0.00
7A	8.25	12	2.49	5.11	2.62	0.50	0.40
7C	8.25	12	0.88	2.05	1.17	0.50	0.20
8A	12.0	12	3.30	5.47	2.17	0.90	0.90
8C	12.0	12	1.27	2.27	1.00	0.50	0.40
9A	4.0	12	1.12	2.85	1.73	0.15	0.15
9D	4.0	12	0.52	1.17	0.65	0.15	0.00
10A	5.0	12	1.55	3.54	1.99	0.40	0.15
10D	5.0	12	0.66	1.08	0.42	0.50	0.00

TABLE VII continued

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss (feet) Initial	Final	Increase	Effluent Turbidity ppm SiO_2 Initial	Final
11A	8.25	12	2.49	4.26	1.77	0.50	0.40
11D	8.25	12	1.14	2.09	0.95	0.25	0.50
12A	12.0	12	3.30	5.03	1.73	0.90	0.50
12D	12.0	12	1.60	2.40	0.80	0.25	0.25
13A	2.4	30	0.65	3.39	2.74	0.00	0.00
13B	2.4	30	0.38	2.06	1.68	0.00	0.00
14A	2.4	12	0.65	2.15	1.50	6.00	5.80
14B	2.4	12	0.38	1.08	0.70	5.40	4.00
15A	5.0	12	1.55	2.79	1.24	9.00	7.20
15B	5.0	12	0.57	1.75	1.18	7.20	5.40

TABLE VIII

SUMMARY OF FILTRATION DATA AND RESULTS WITH 100 ppm KAOLIN INFLUENT

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss (feet) Initial	Final	Increase	Effluent Turbidity % light transmission Initial	Final
16E	2.0	12	0.24	0.75	0.51	66.0	58.0
16F	2.0	12	0.15	0.71	0.56	71.0	62.0
16G	2.0	12	0.06	0.41	0.35	70.0	59.0
16H	2.0	12	0.11	0.31	0.20	75.0	67.0
17E	4.0	12	0.47	1.24	0.77	61.0	43.0
17F	4.0	12	0.29	1.07	0.78	63.0	50.0
17G	4.0	12	0.13	0.86	0.73	64.0	46.0
17H	4.0	12	0.21	0.73	0.52	69.0	57.0

TABLE IX

SUMMARY OF TOTAL HEAD LOSS INCREASE BETWEEN DIFFERENT ORIFICES

FILTERS A AND B

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss Increase (feet) Top of Media to M-4	Top of Media to M-10	Between M-4 & M-10
1A	2.4	16	1.48	1.49	0.01
1B	2.4	16	0.85	0.85	0.00
2A	5.0	12	2.76	2.77	0.01
2B	5.0	12	1.37	1.38	0.01
3A	10.0	12	2.87	2.87	0.00
3B	10.0	12	2.00	2.00	0.00
4A	12.0	12	2.94	2.94	0.00
4B	12.0	12	2.70	2.75	0.05
13A	2.4	30	2.69	2.74	0.05
13B	2.4	30	1.64	1.68	0.04
14A	2.4	12	1.14	1.50	0.36
14B	2.4	12	0.43	0.70	0.27
15A	5.0	12	1.01	1.24	0.23
15B	5.0	12	0.95	1.18	0.23

TABLE X

SUMMARY OF TOTAL HEAD LOSS INCREASE BETWEEN DIFFERENT ORIFICES

FILTERS A AND C

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss Increase (feet) Top of Media to M-4	Top of Media to M-10	Between M-4 & M-10
5A	3.0	12	1.33	1.36	0.03
5C	3.0	12	0.28	0.40	0.12
6A	5.0	12	2.42	2.42	0.00
6C	5.0	12	0.70	0.89	0.19
7A	8.25	12	2.59	2.62	0.03
7C	8.25	12	0.89	1.17	0.28
8A	12.0	12	2.15	2.17	0.02
8C	12.0	12	0.78	1.00	0.22

TABLE XI

SUMMARY OF TOTAL HEAD LOSS INCREASE BETWEEN DIFFERENT ORIFICES

FILTERS A AND D

Run	Rate U.S. gpm/ sq. ft.	Duration Hours	Total Head Loss Increase (feet) Top of Media to M-3	M-6	M-10	Between M-3 & M-6	M-6 & M-10
9A	4.0	12	1.72	1.72	1.73	0.00	0.01
9D	4.0	12	0.48	0.56	0.65	0.08	0.09
10A	5.0	12	1.99	1.99	1.99	0.00	0.00
10D	5.0	12	0.32	0.37	0.42	0.05	0.05
11A	8.25	12	1.77	1.77	1.77	0.00	0.00
11D	8.25	12	0.81	0.92	0.95	0.09	0.03
12A	12.0	12	1.73	1.73	1.73	0.00	0.00
12D	12.0	12	0.56	0.67	0.80	0.11	0.03

TABLE XII

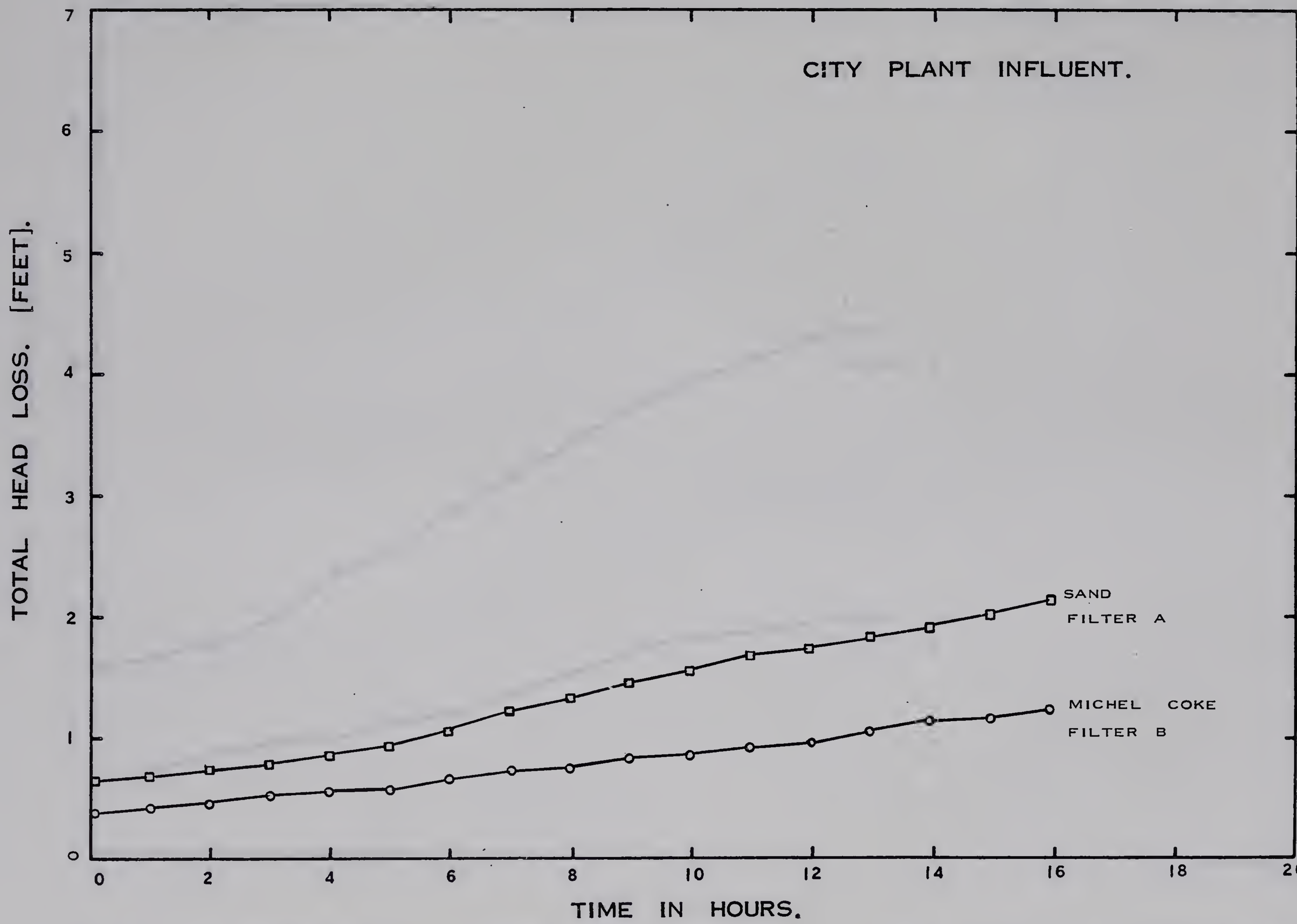
SUMMARY OF TOTAL HEAD LOSS BEFORE USE AND AFTER USE OF MEDIA FOR FILTERS A AND B

Rate U.S. gpm/ sq. ft.	SAND FILTER A		MICHEL COKE FILTER B	
	Initial Head Loss-feet	Final Head Loss-feet	Initial Head Loss-feet	Final Head Loss-feet
2.4	0.65	0.65	0.38	0.38
5.0	1.55	1.55	0.57	0.57
10.0	2.75	2.75	1.10	1.10
12.0	3.30	3.30	1.42	1.42

TABLE XIII

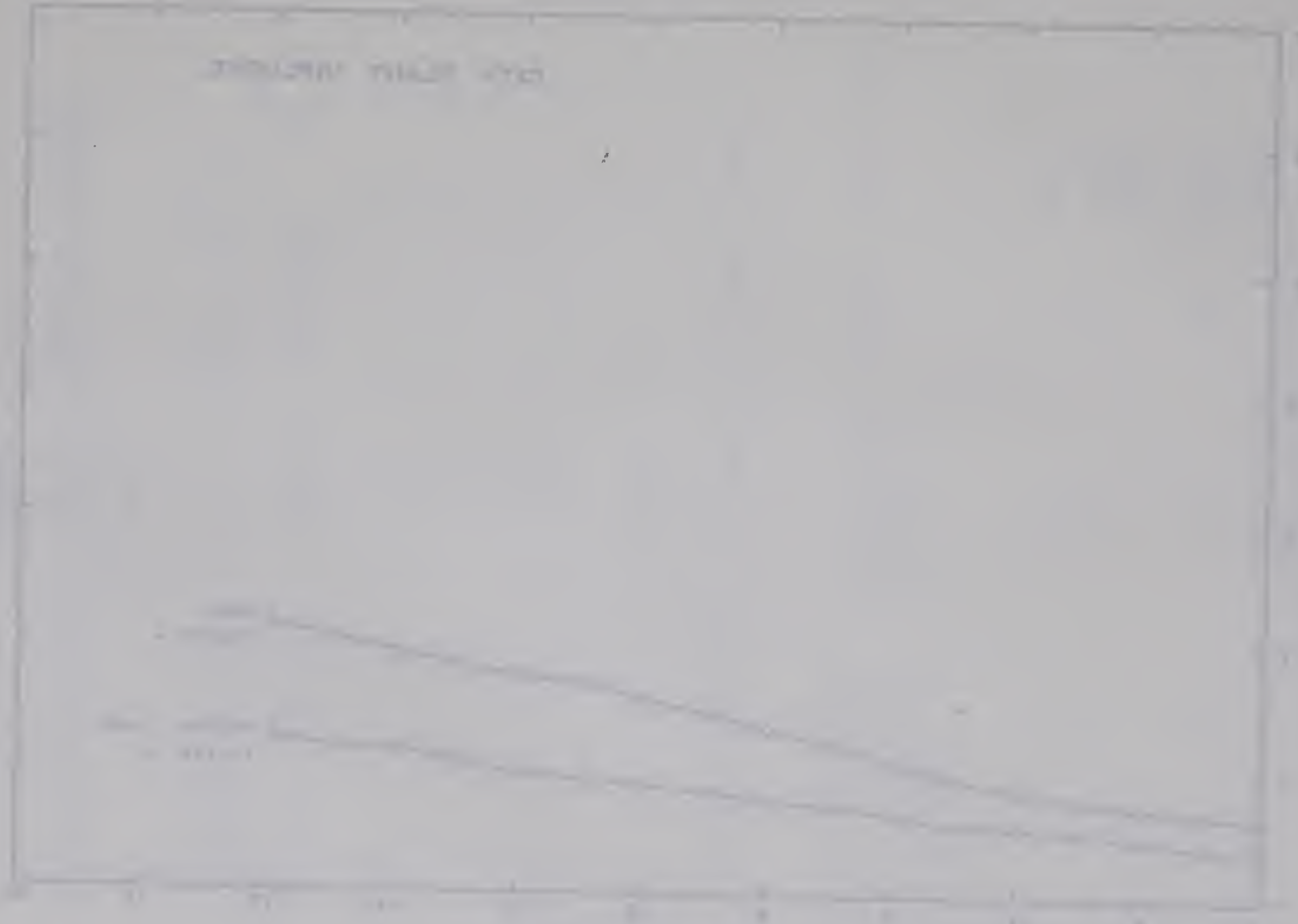
SPECIFIC SURFACE AREA, POROSITY AND FILTRATION TEST RESULTS

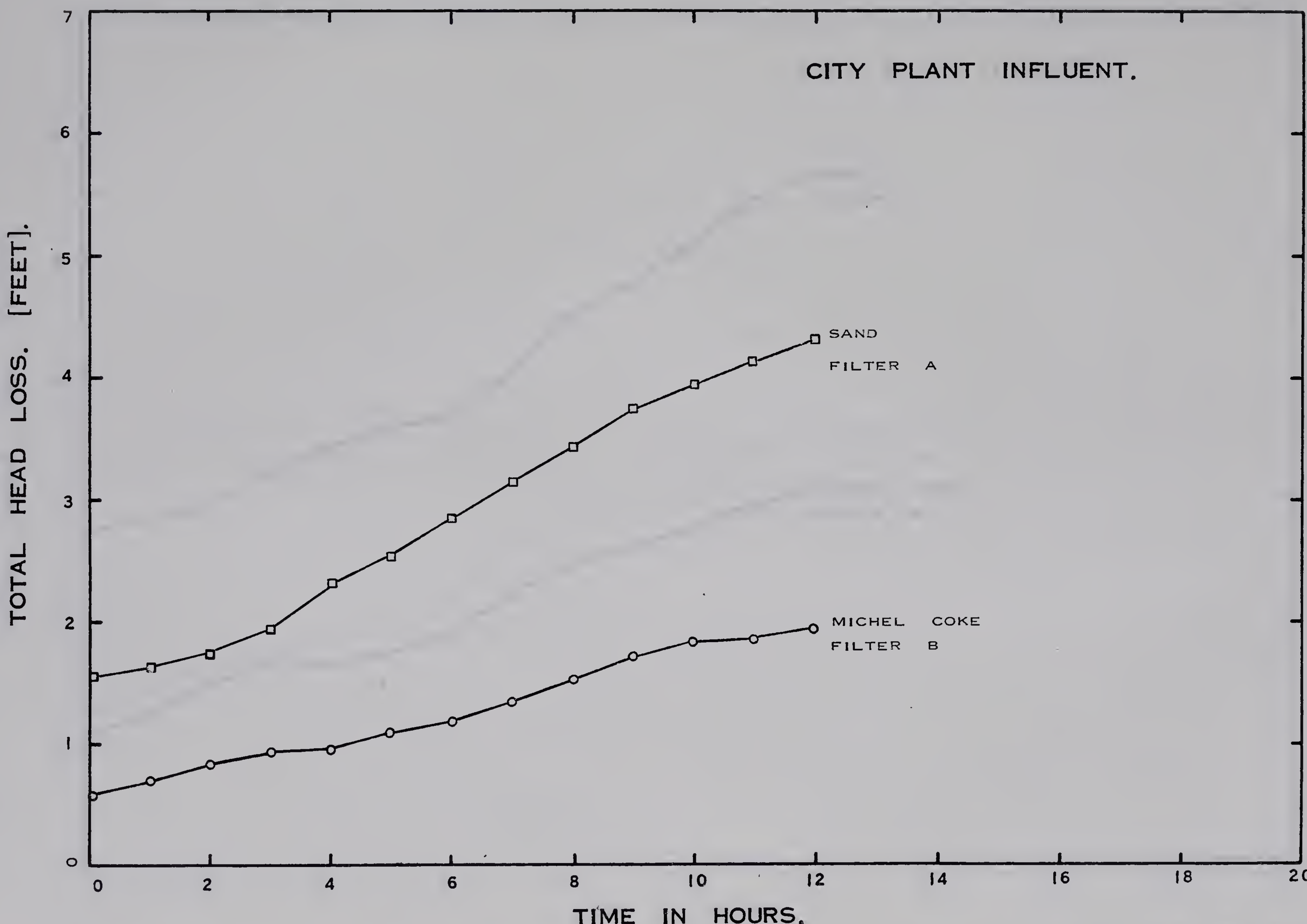
Filter	Media	Porosity %	Specific Surface area sq. meter/gram	Typical Filtration Results	
				Head Loss after 12 hr at 2.0 gpm/ ft^2 (feet)	Turbidity after 12 hr at 2.0 U.S. gpm/ft^2 % transmission
E	Sand	41	0.60	0.75	58
F	Rough Michel Coke	66	24.3	0.31	67
G	Tumbled Michel Coke	58	3.4	0.41	60



RUN I A AND I B. HEAD LOSS CURVES. 2.4 U.S. GPM PER SQ. FT.

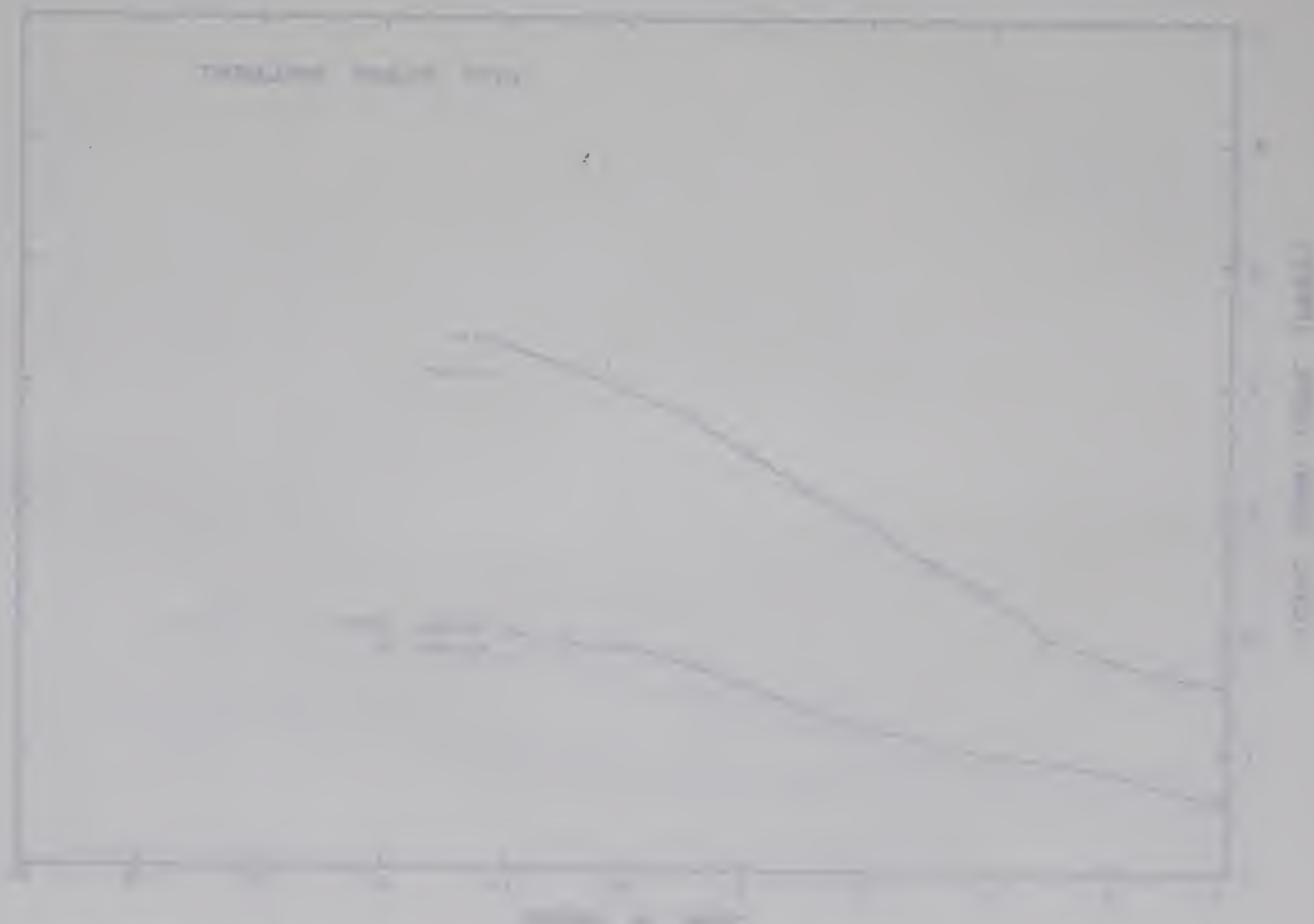
FIGURE 7.

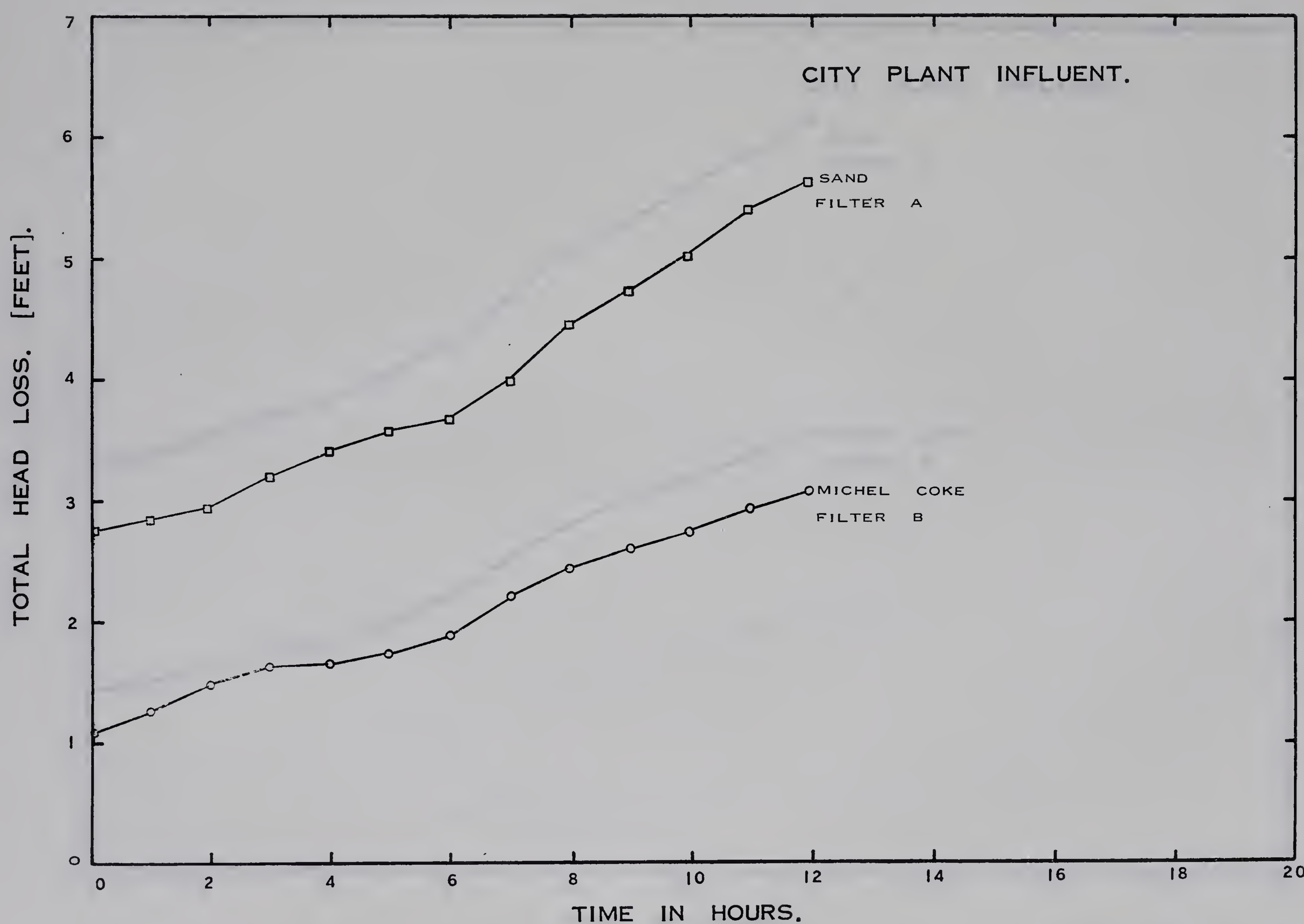




RUN 2 A AND 2B. HEAD LOSS CURVES. 5.0 U.S. GPM PER SQ.FT.

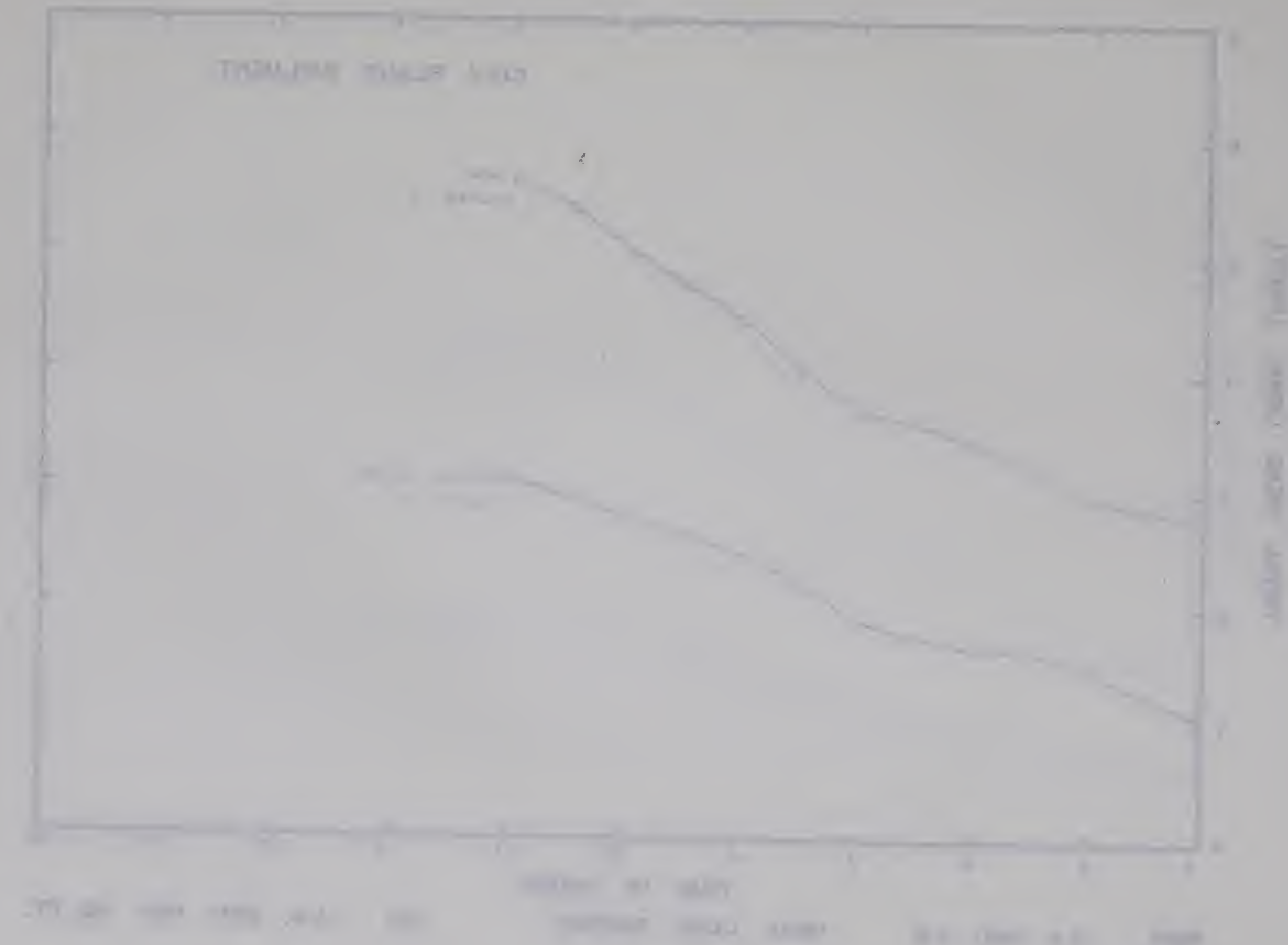
FIGURE 8.

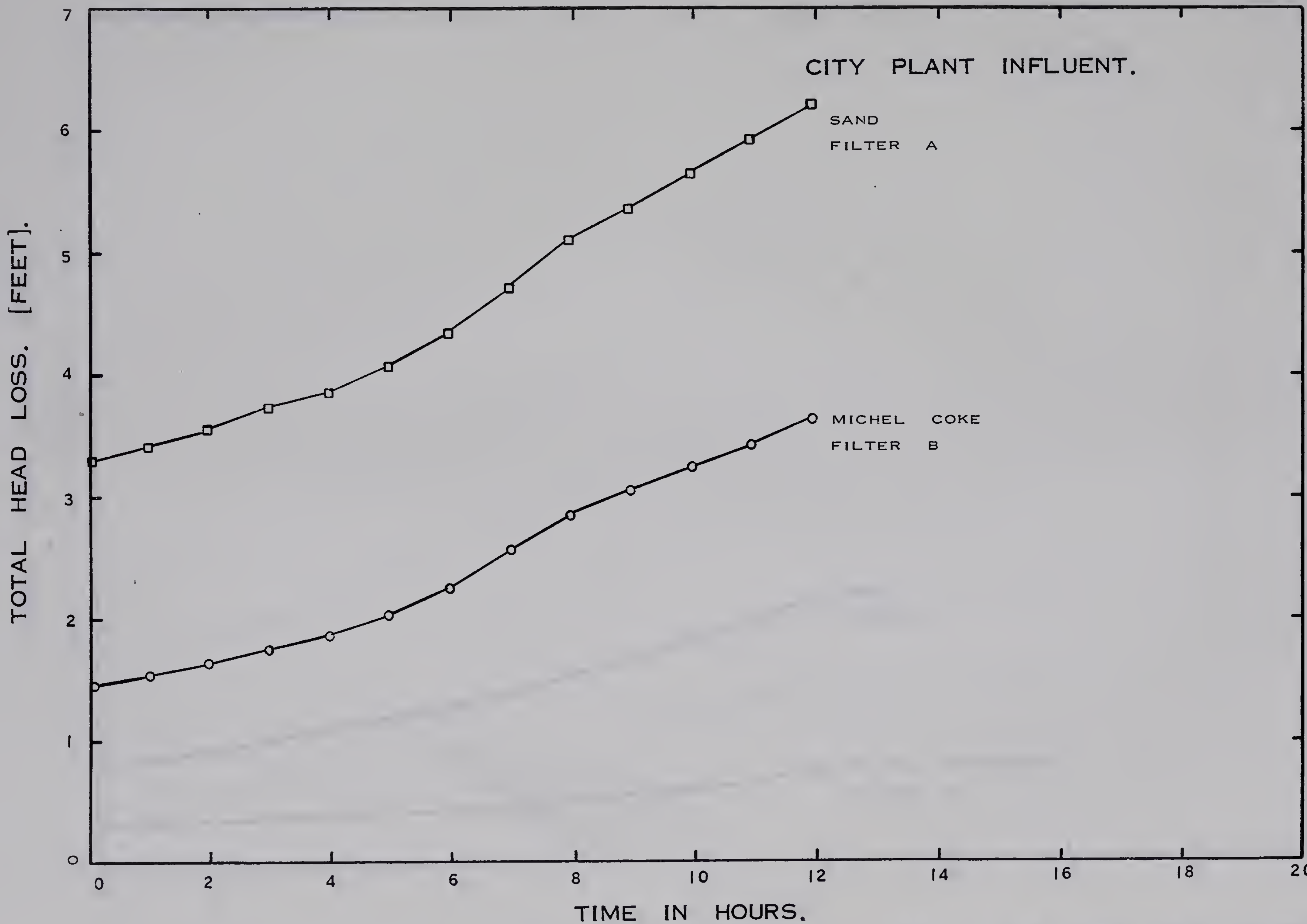




RUN 3 A AND 3 B. HEAD LOSS CURVES. 10.0 U.S. GPM PER SQ. FT.

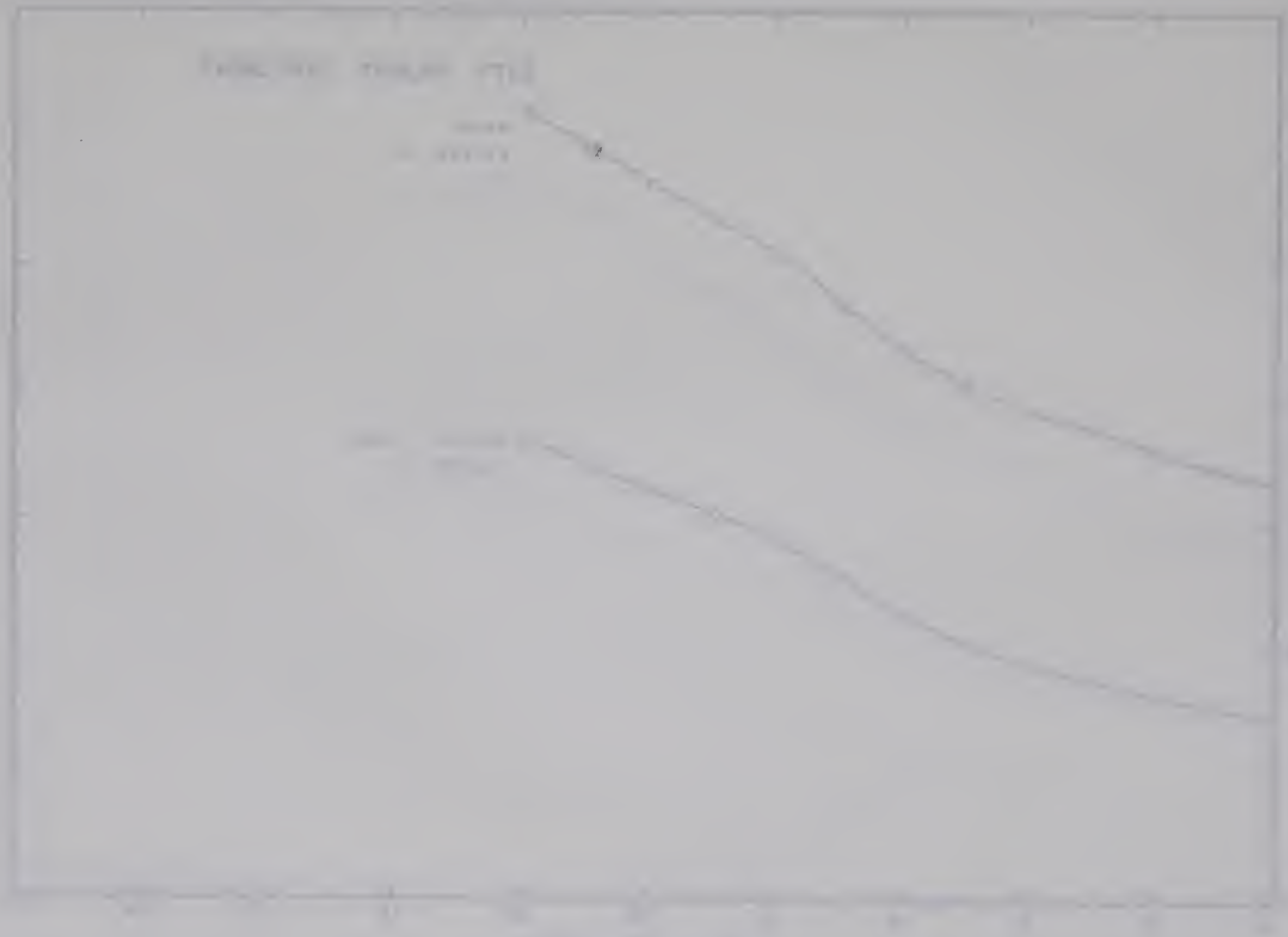
FIGURE 9.

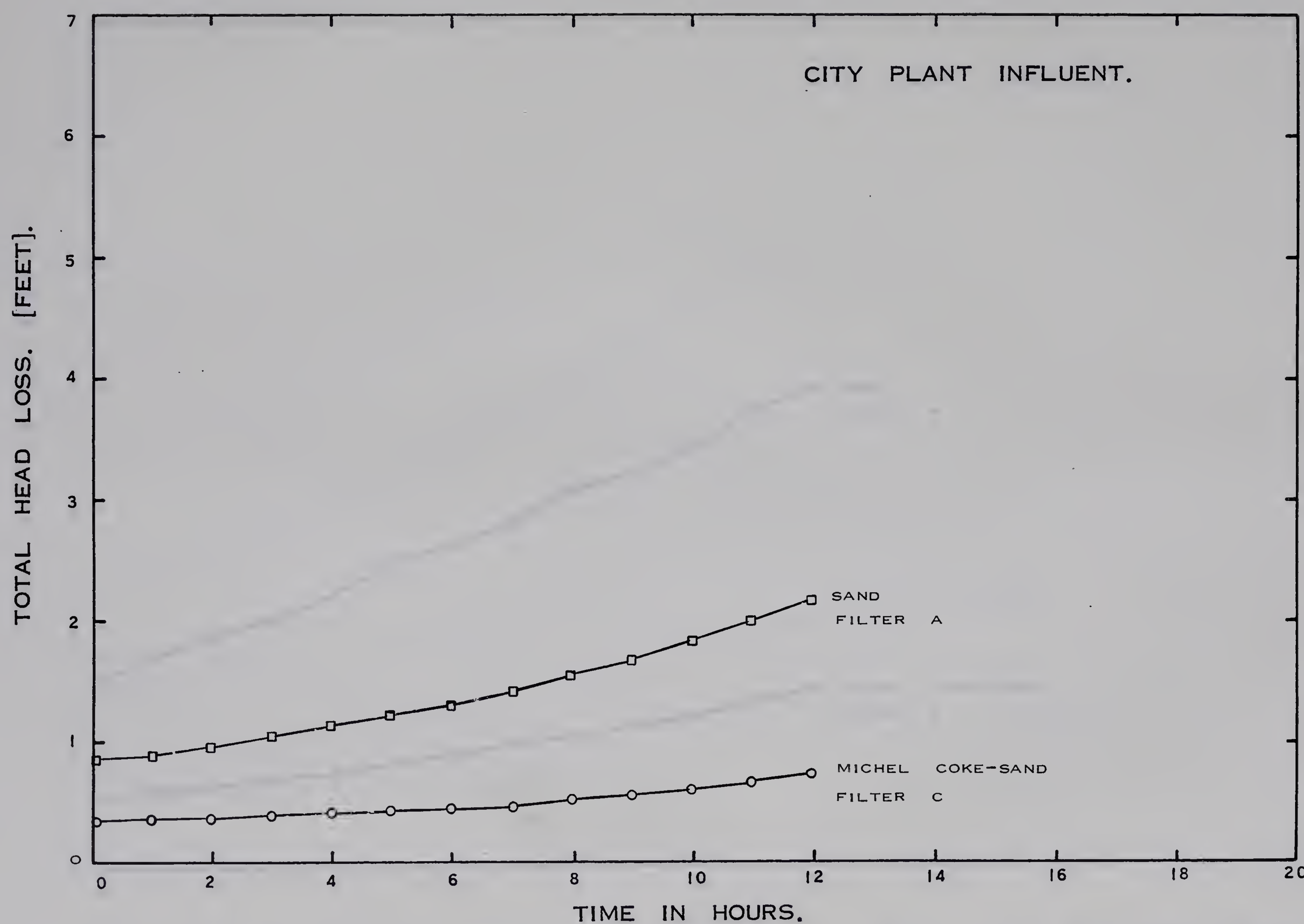




RUN 4 A AND 4 B. HEAD LOSS CURVES. 12.0 U.S. GPM PER SQ.FT.

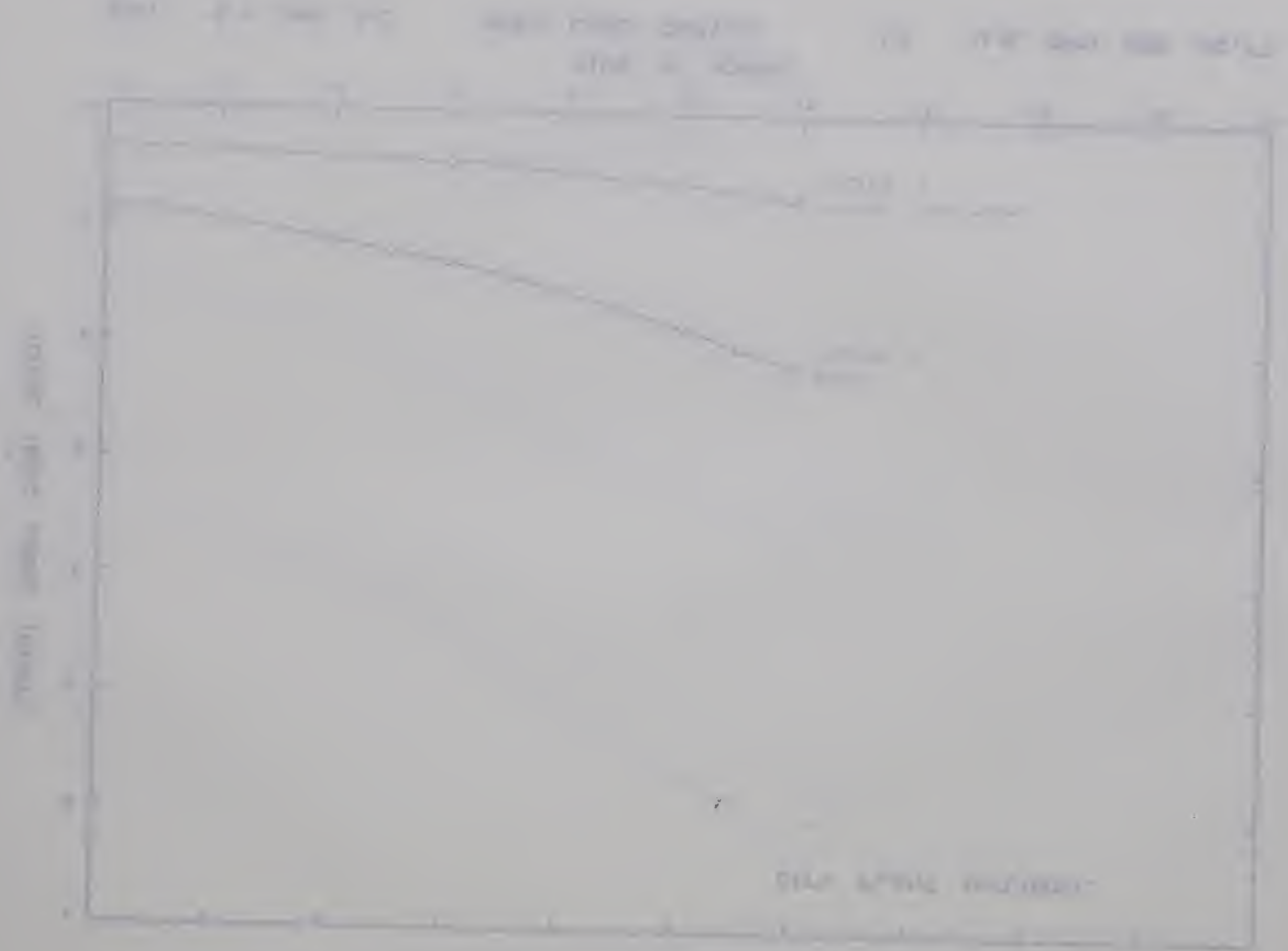
FIGURE 10.

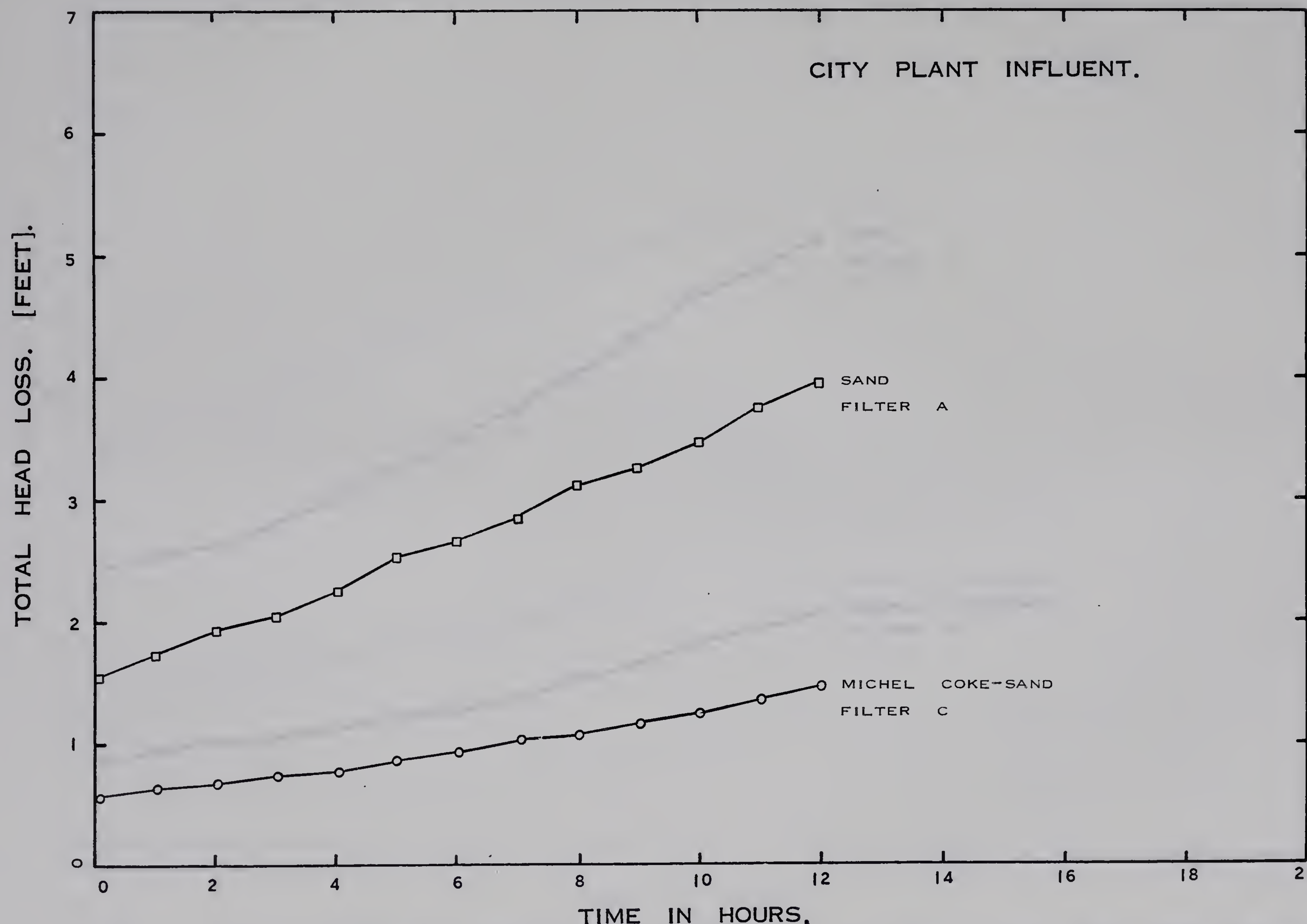




RUN 5 A AND 5 C. HEAD LOSS CURVES. 3.0 U.S. GPM PER SQ.FT.

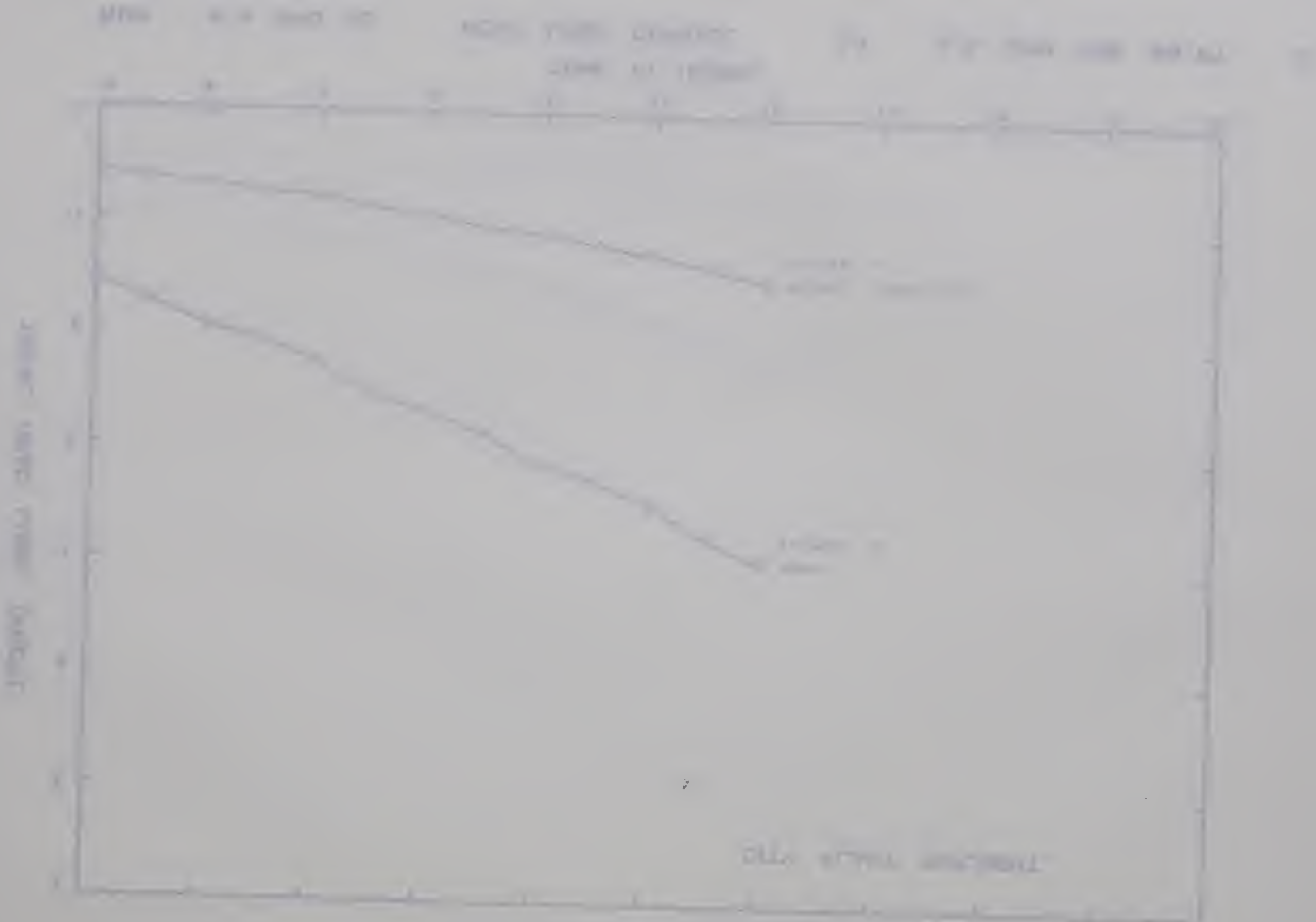
FIGURE II.

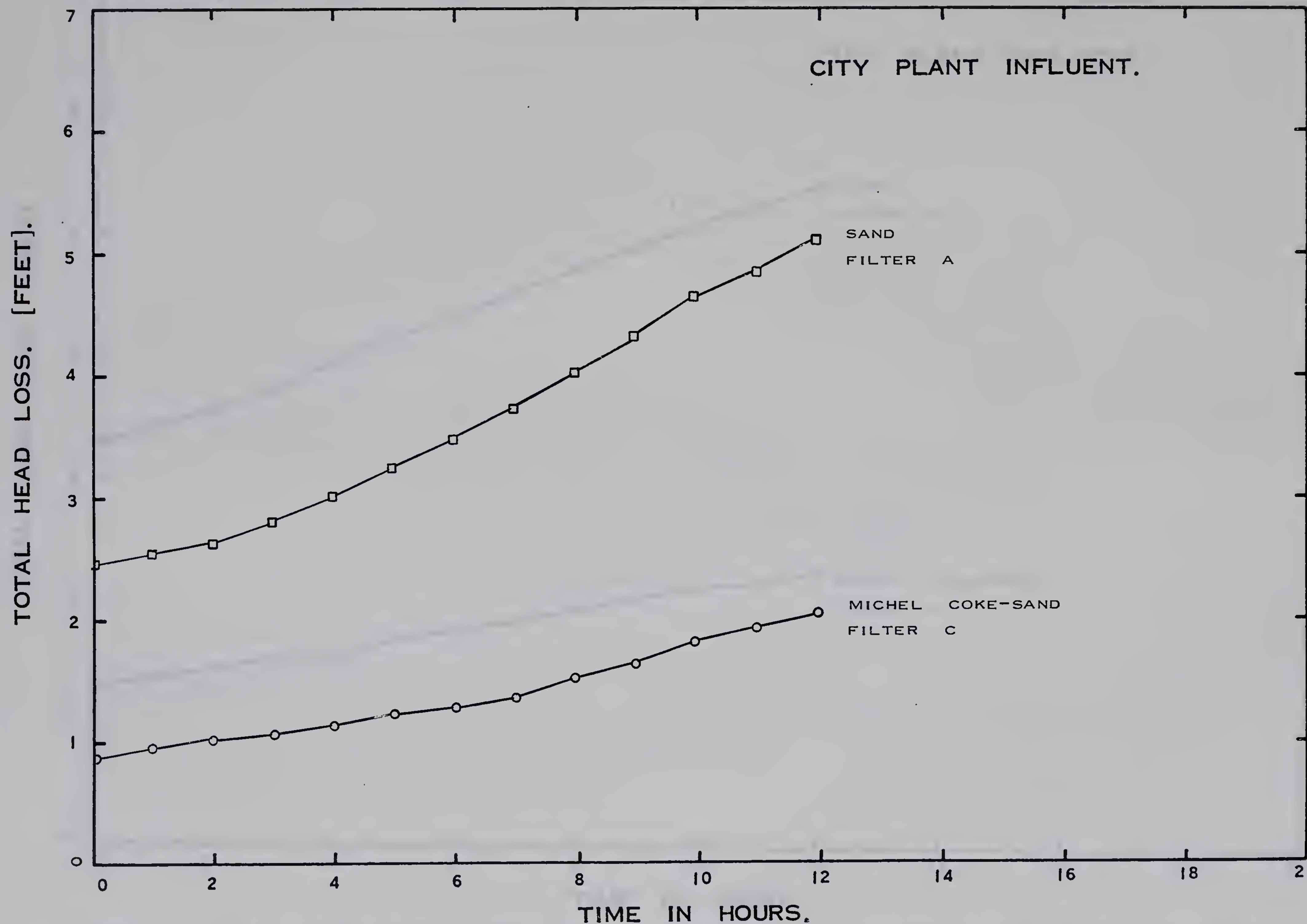




RUN 6 A AND 6C. HEAD LOSS CURVES. 5.0 U.S. GPM PER SQ.FT.

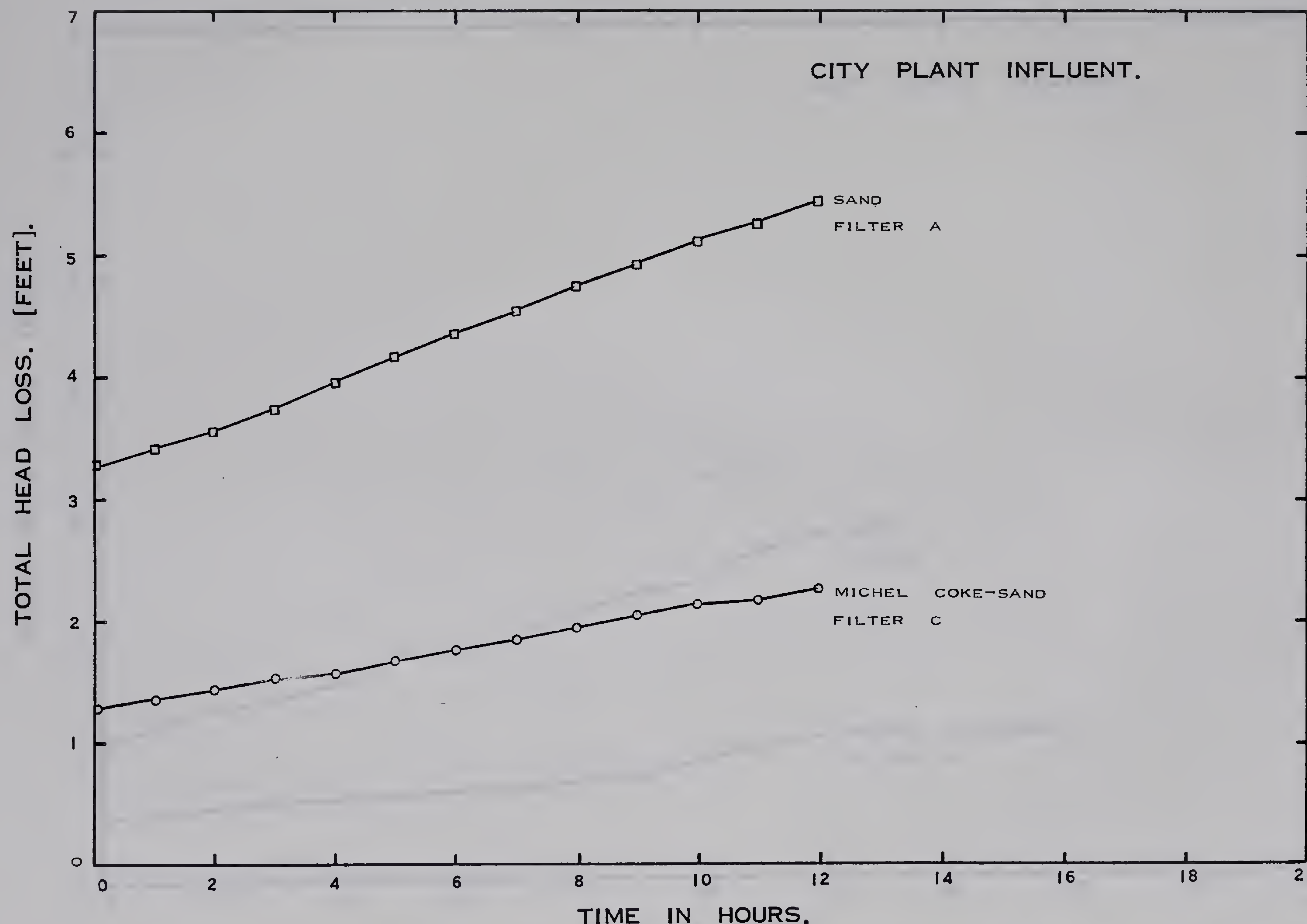
FIGURE 12.





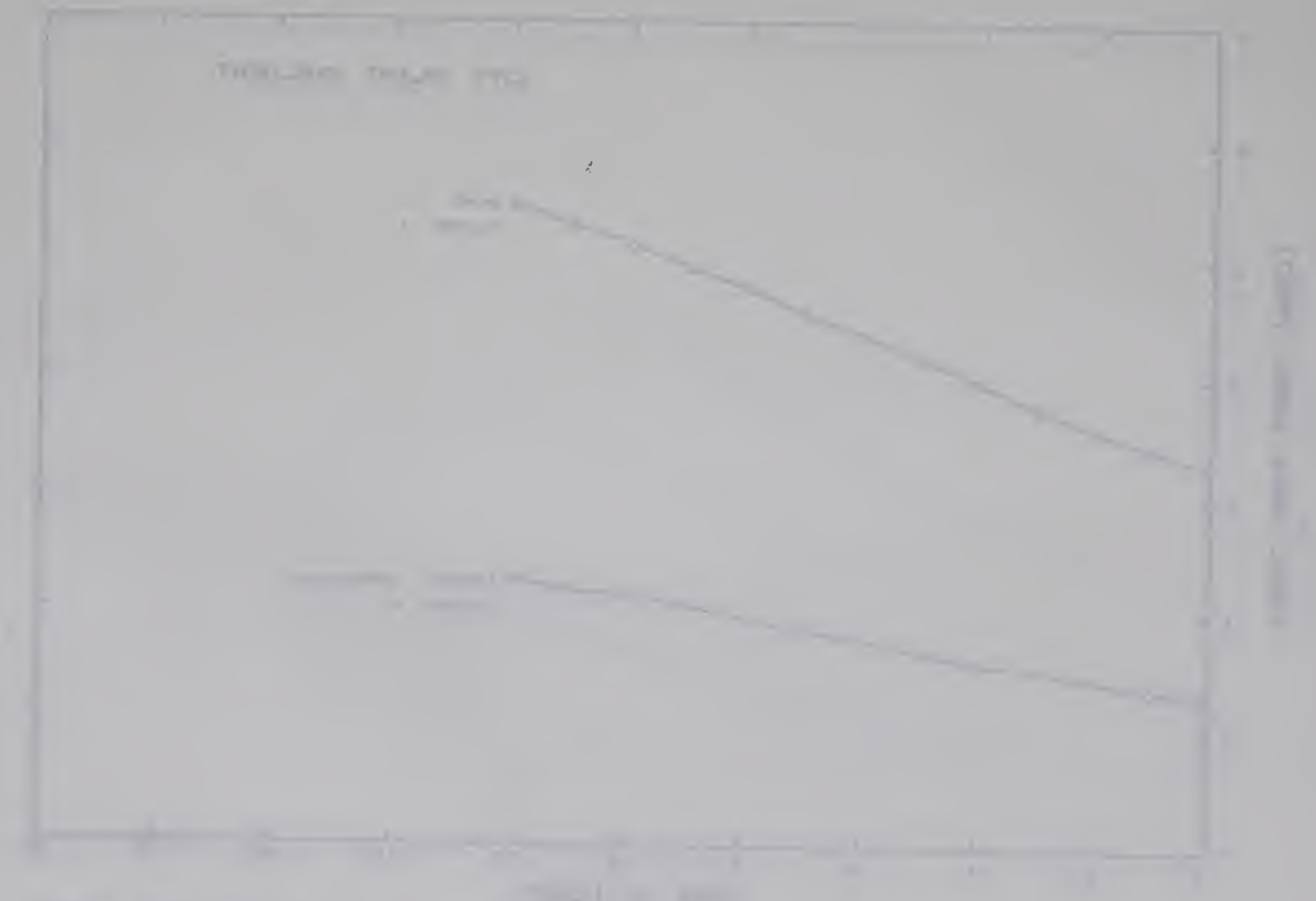
RUN 7 A AND 7C. HEAD LOSS CURVES. 8.25 U.S. GPM PER SQ.FT.

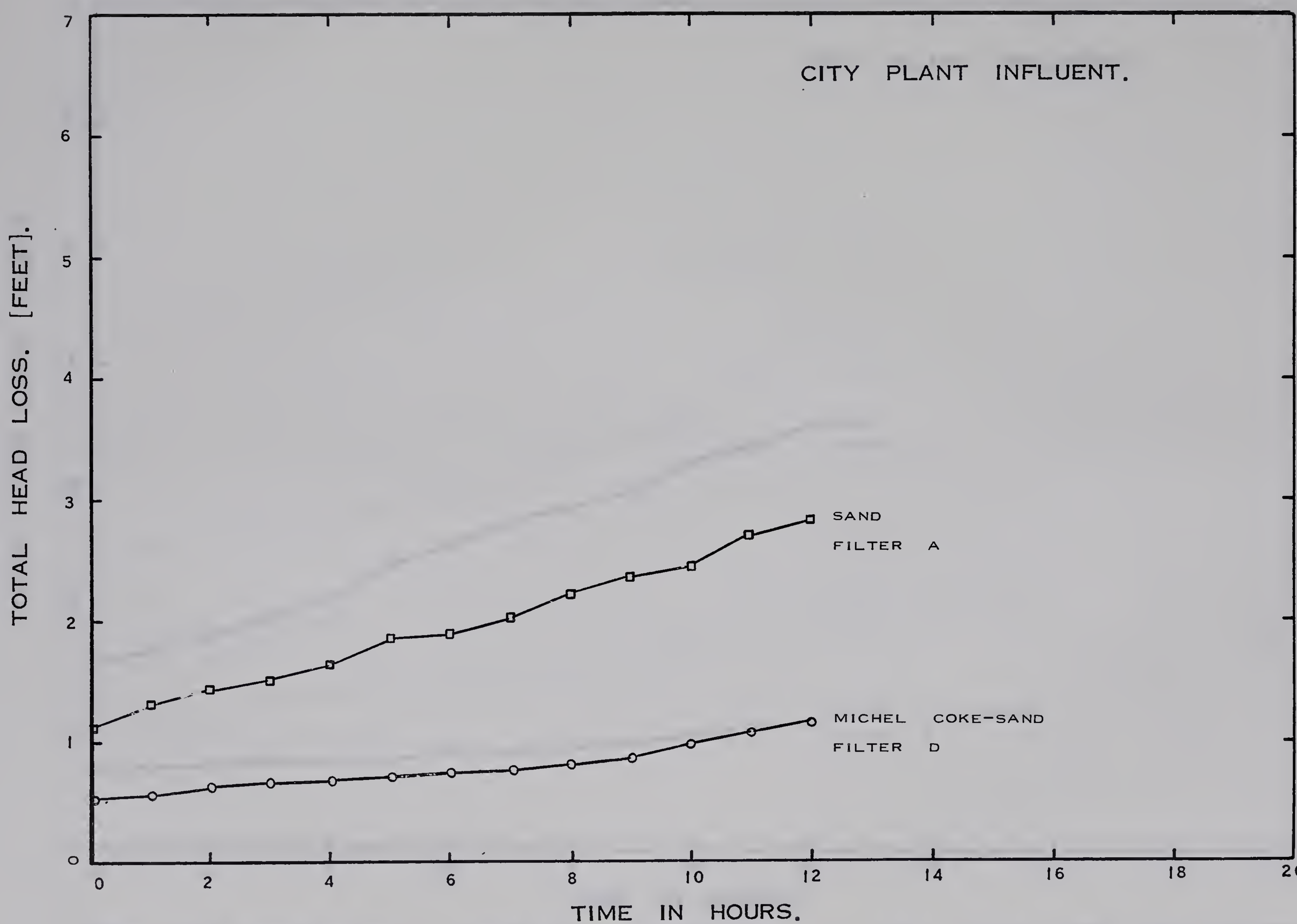
FIGURE 13.



RUN 8 A AND 8 C. HEAD LOSS CURVES. 12.0 U.S. GPM PER SQ.FT.

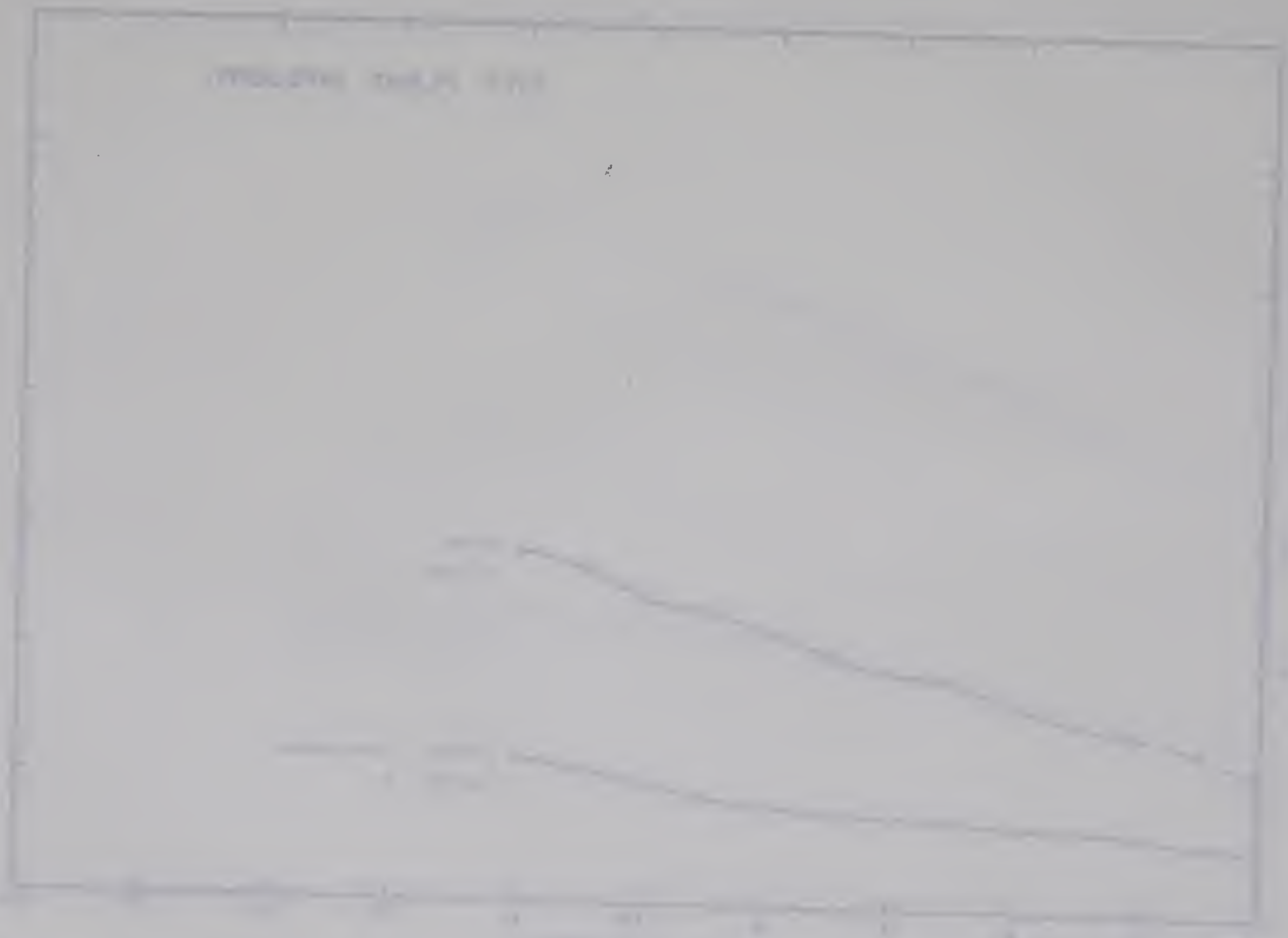
FIGURE 14.

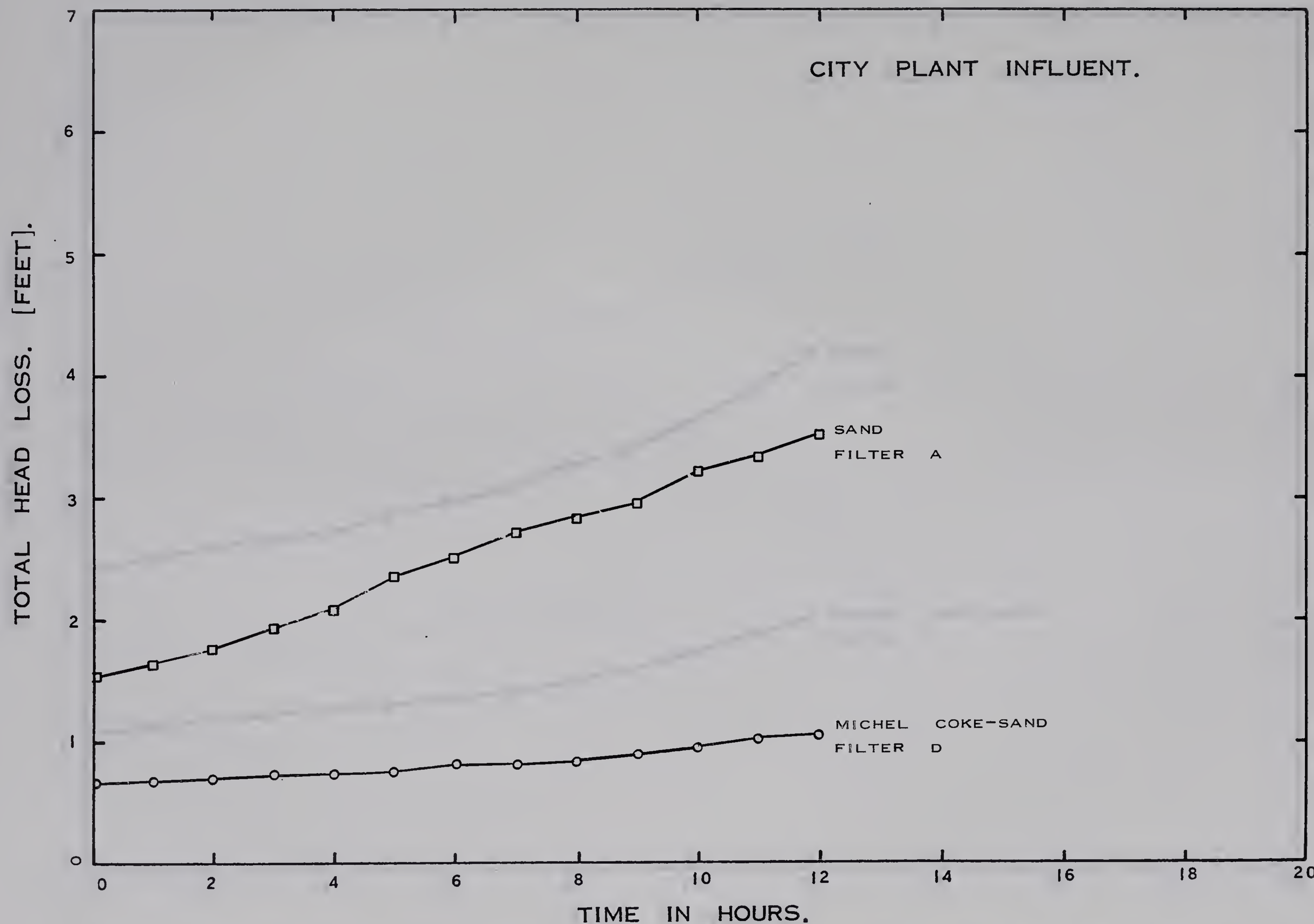




RUN 9 A AND 9 D. HEAD LOSS CURVES. 4.0 U.S. GPM PER SQ.FT.

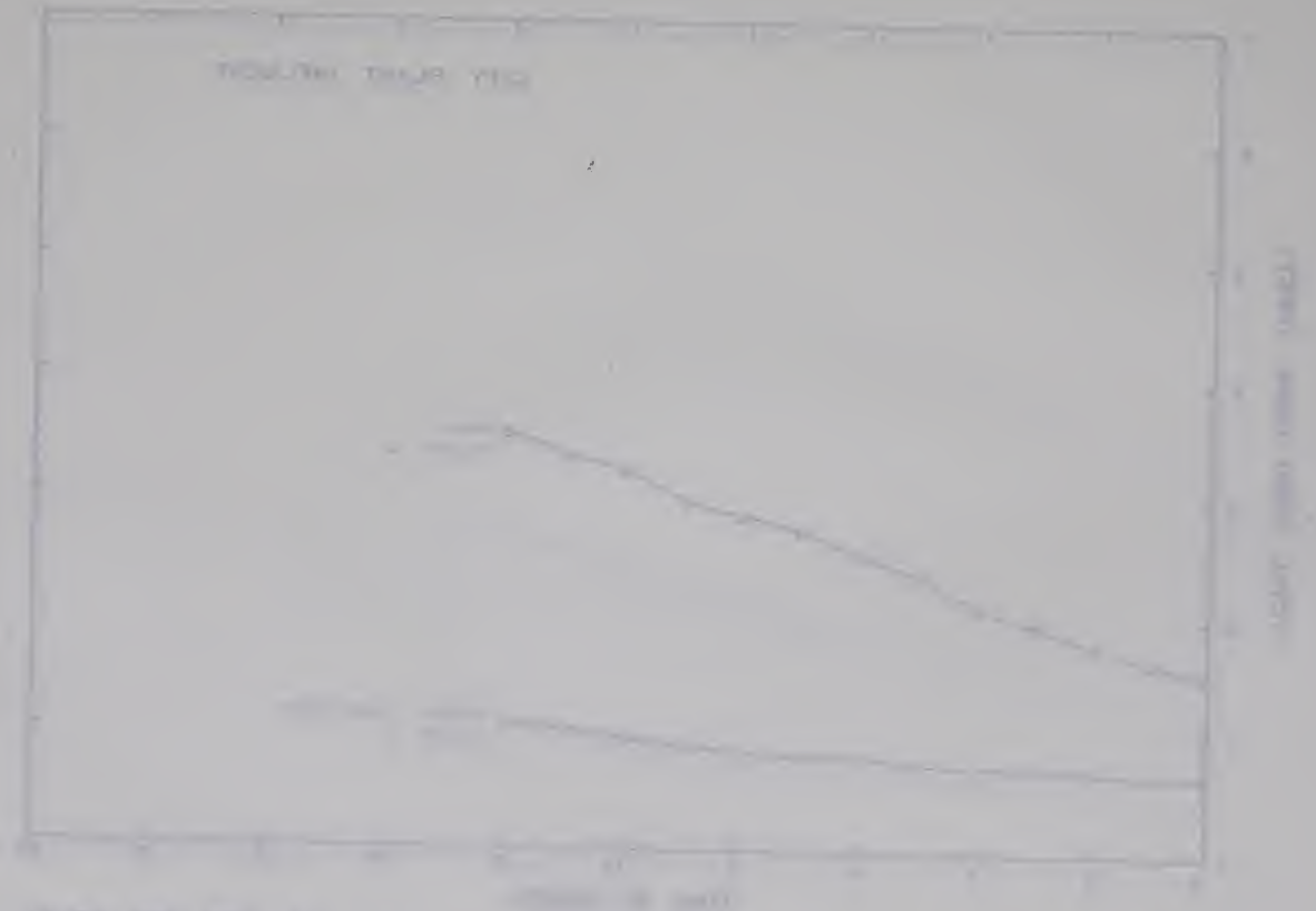
FIGURE 15.

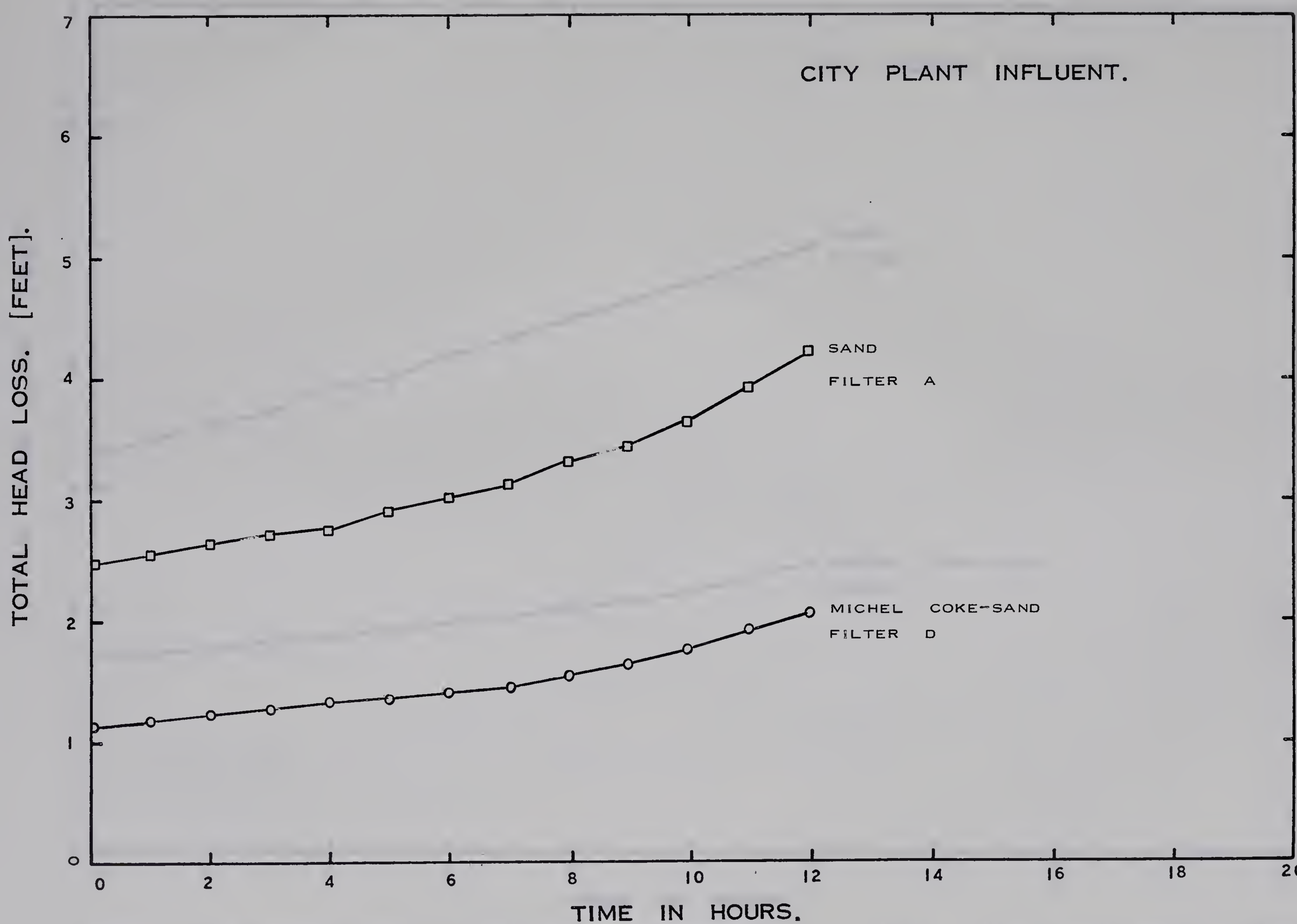




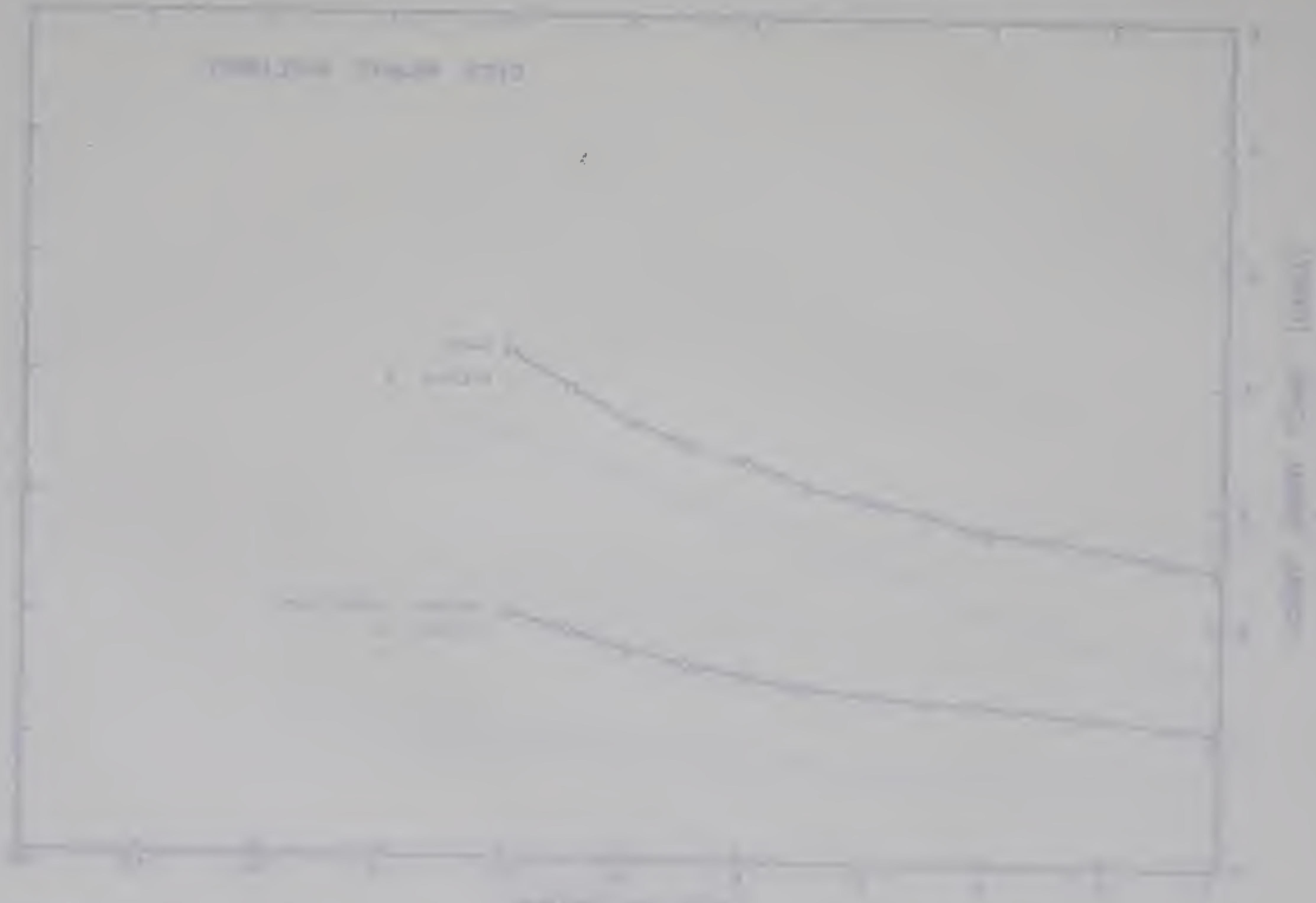
RUN 10 A AND 10 D. HEAD LOSS CURVES. 5.0 U.S. GPM PER SQ.FT.

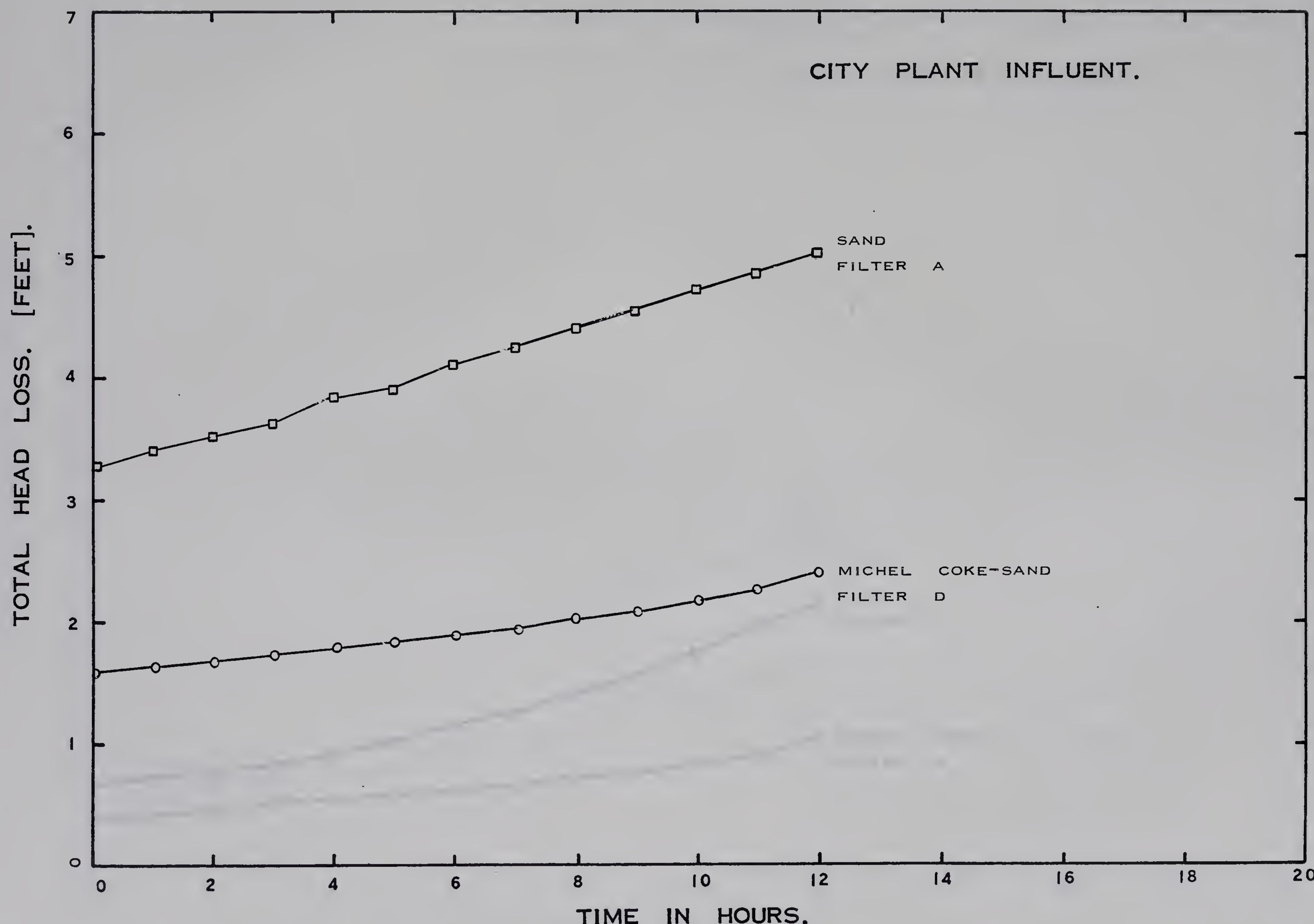
FIGURE 16.





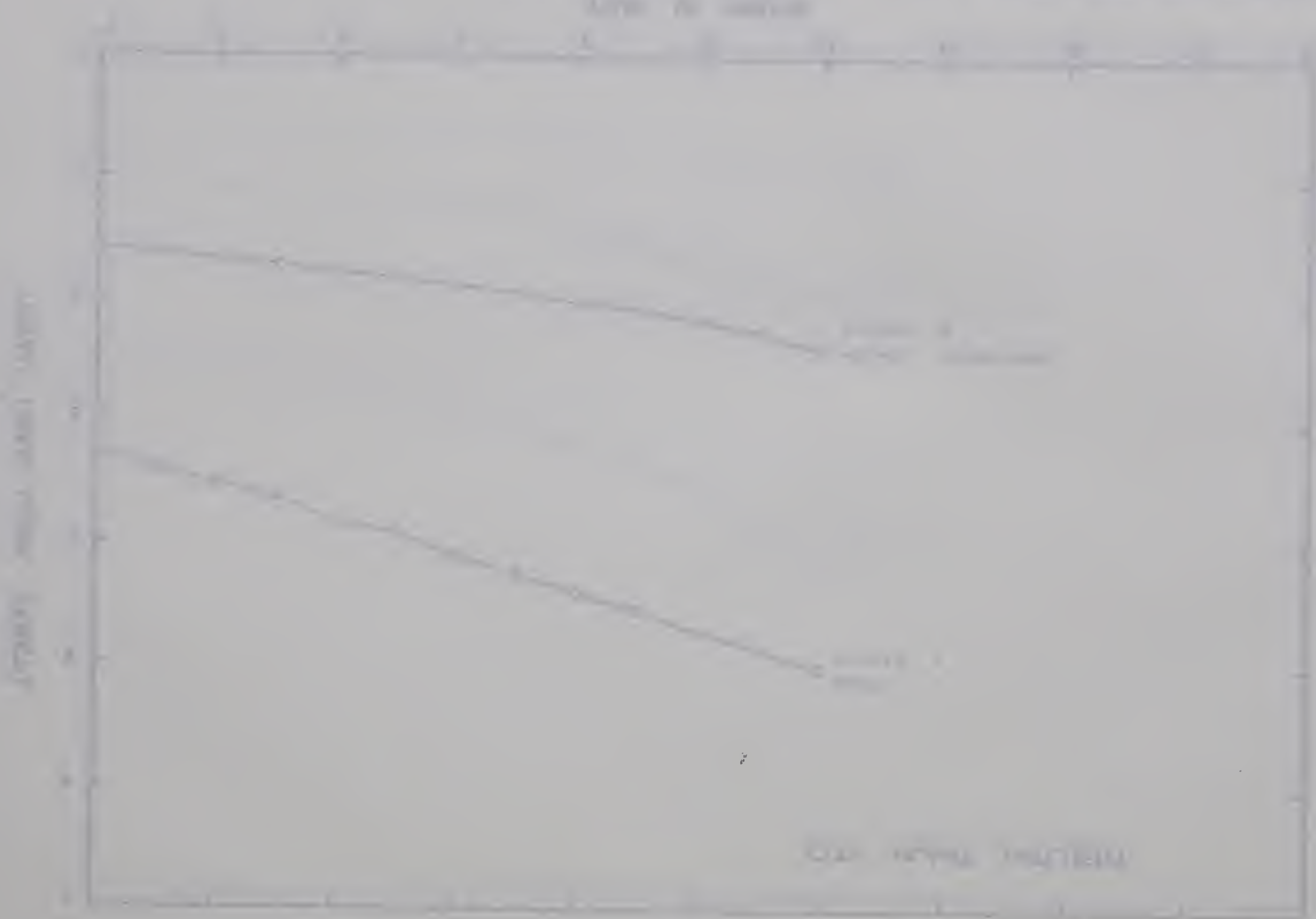
RUN II A AND II D. HEAD LOSS CURVES. 8.25 U.S. GPM PER SQ.FT.
FIGURE 17.

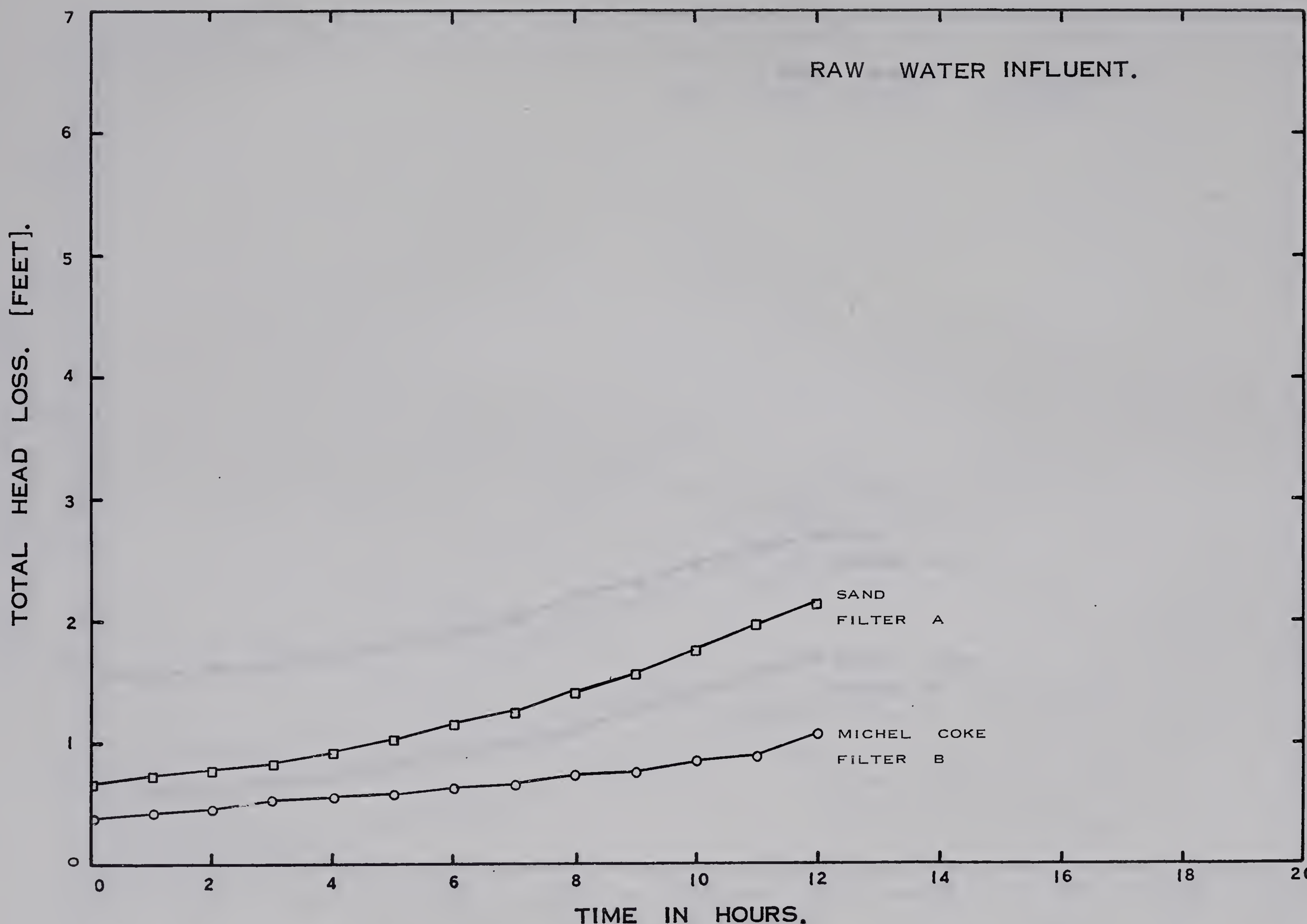




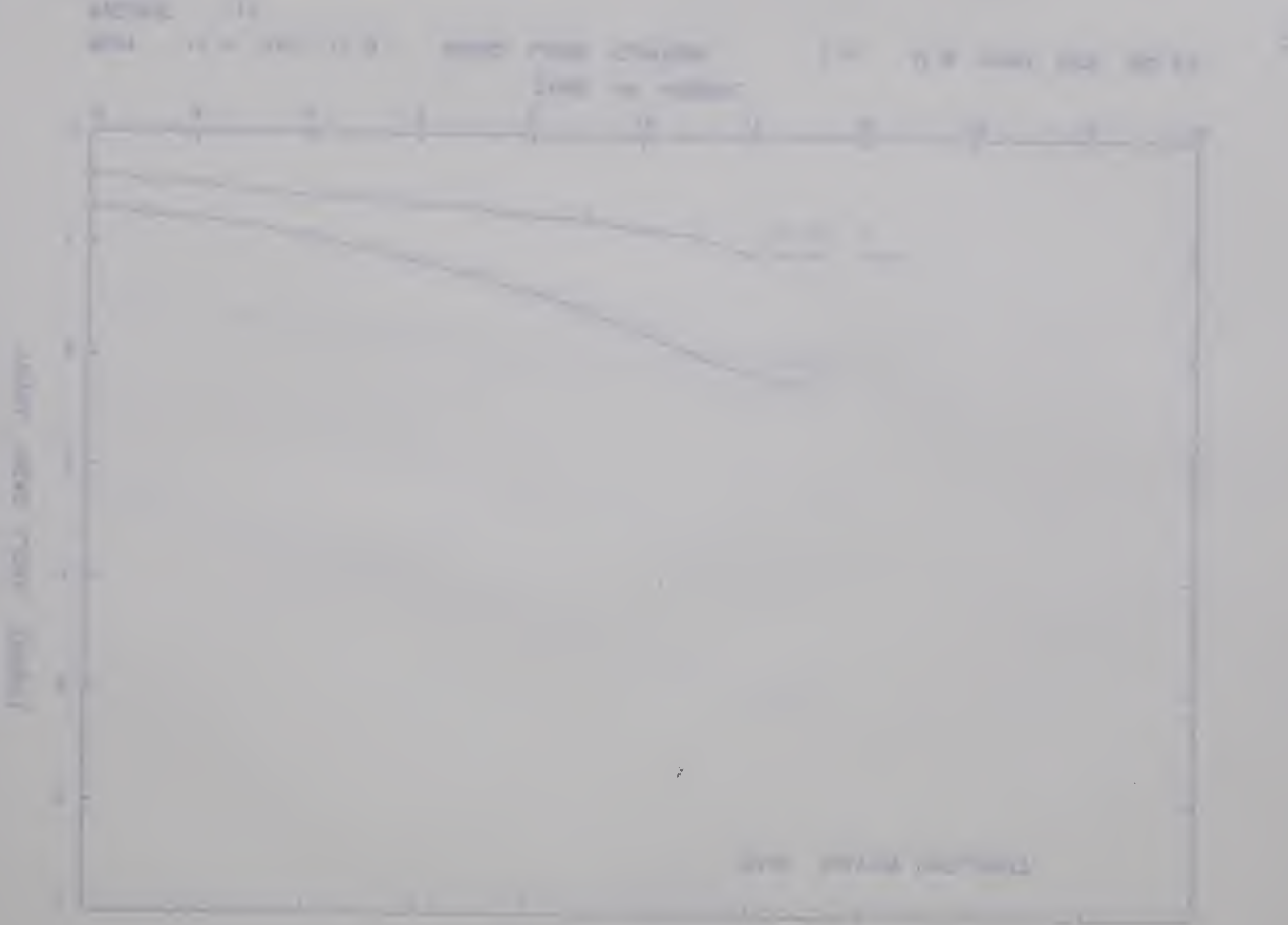
RUN 12 A AND 12 D. HEAD LOSS CURVES. 12.0 U.S. GPM PER SQ.FT.

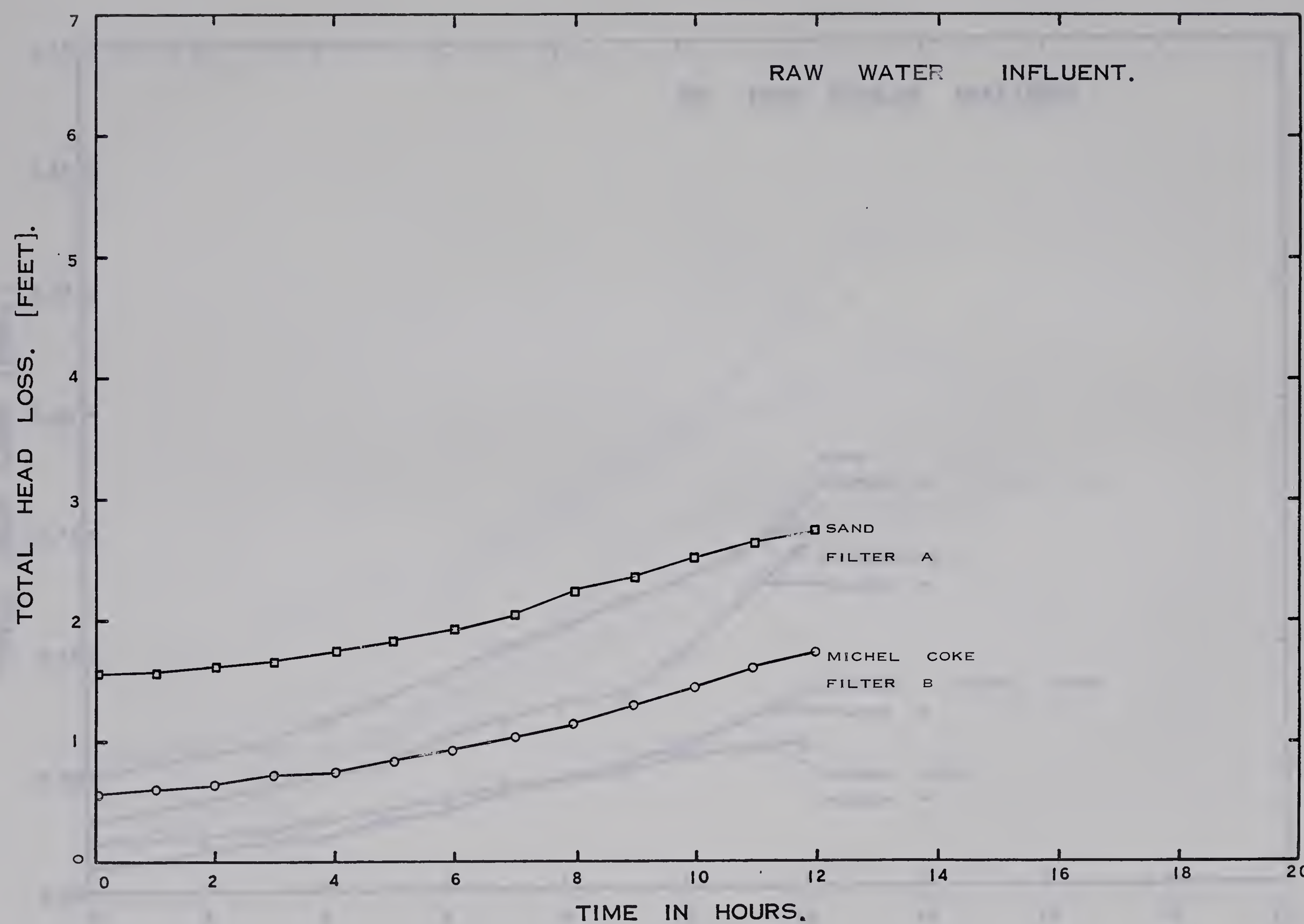
FIGURE 18.





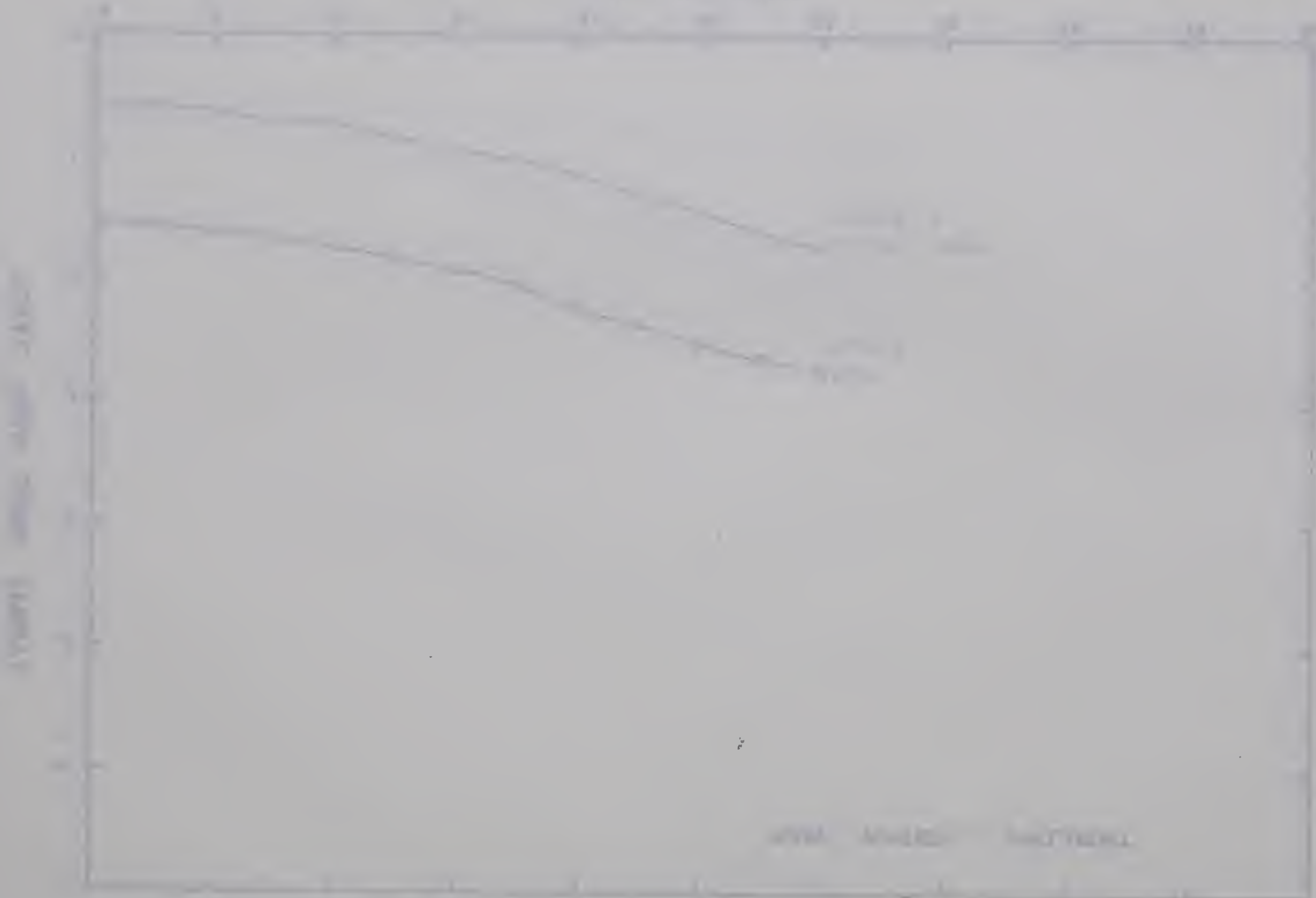
RUN 14 A AND 14 B. HEAD LOSS CURVES. 2.4 U.S. GPM PER SQ.FT.
FIGURE 19.

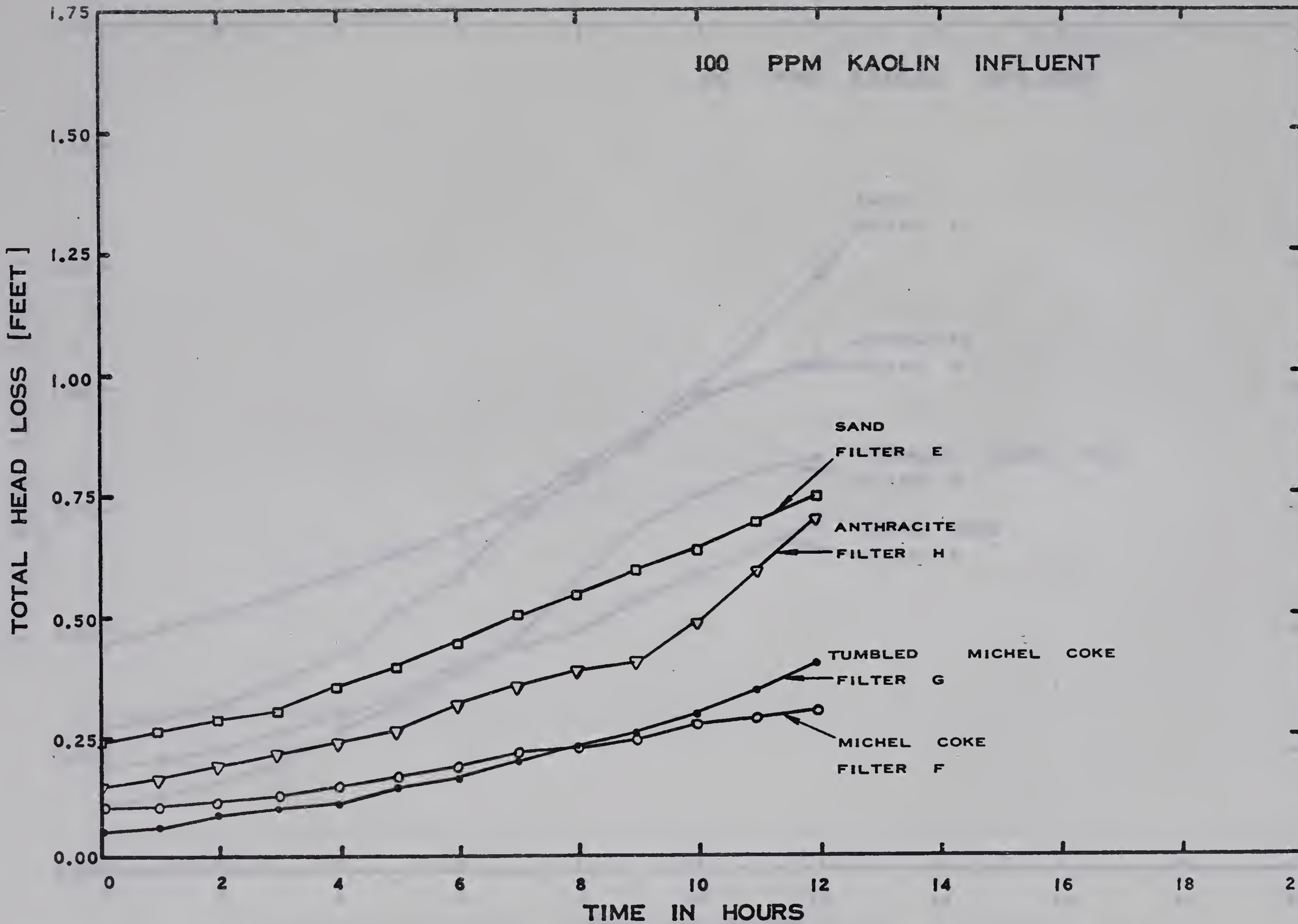




RUN 15 A AND 15 B. HEAD LOSS CURVES. 5.0 U.S. GPM PER SQ.FT.

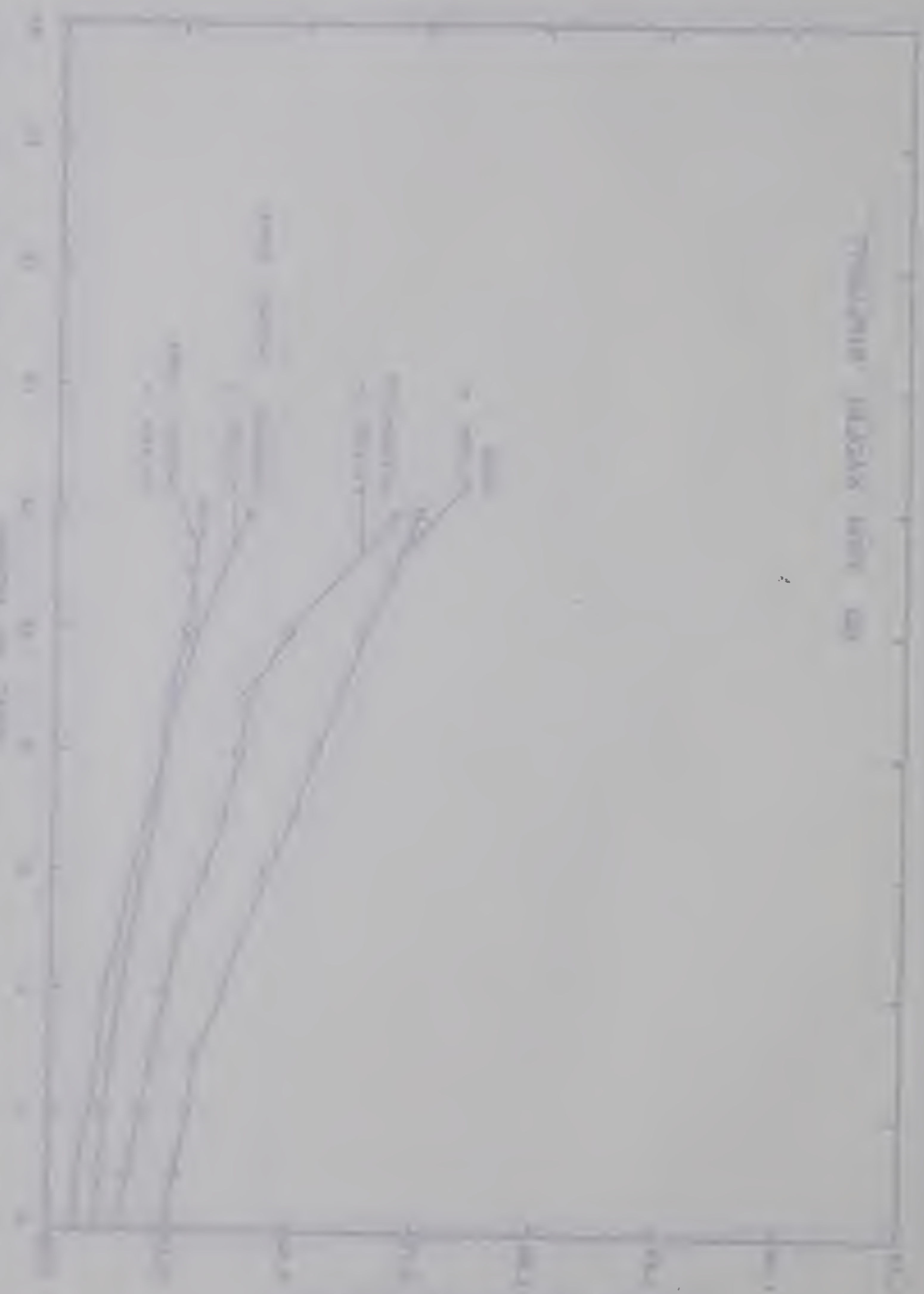
FIGURE 20.

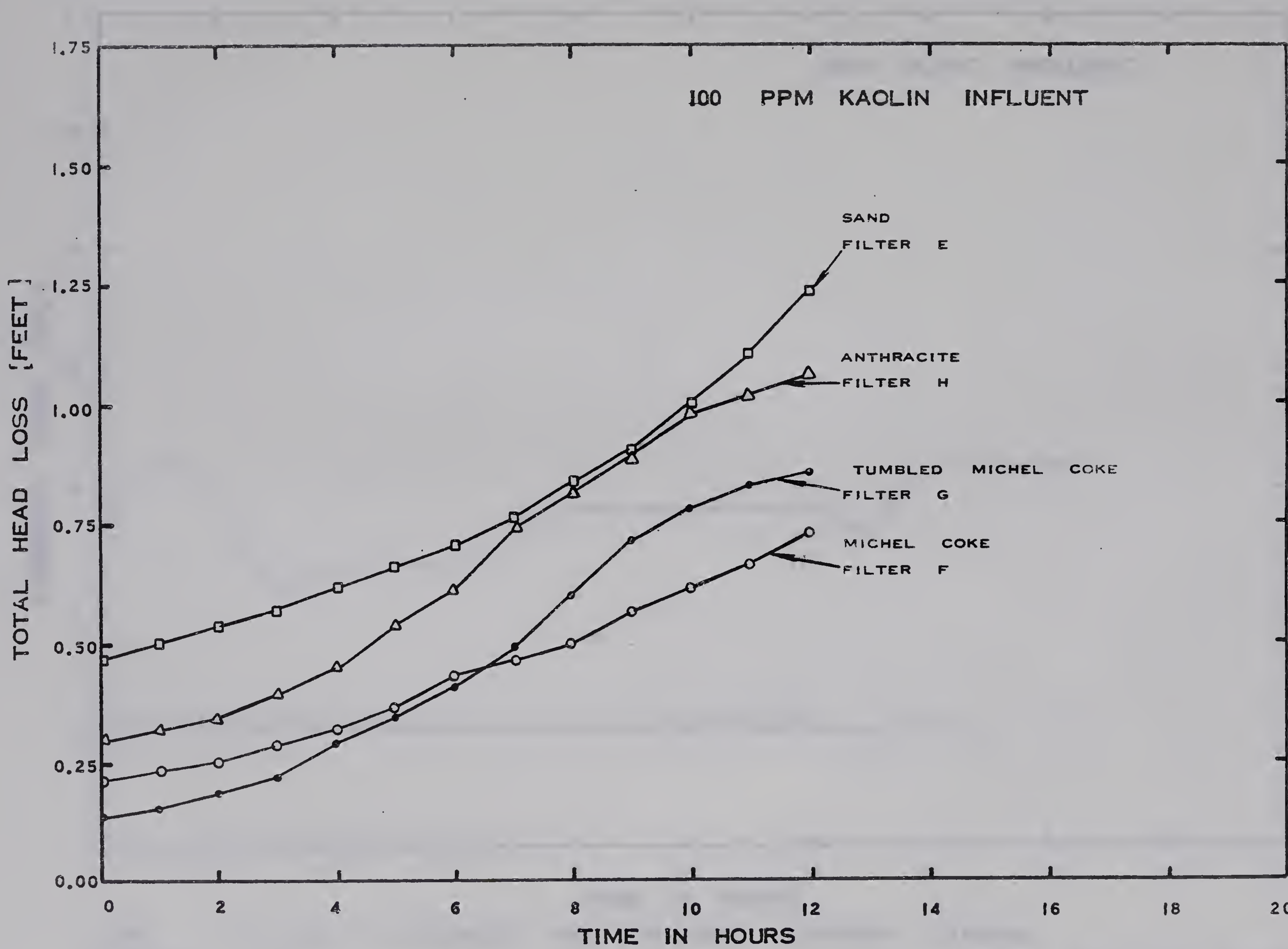




RUN 16 E, 16 F, 16 G AND 16 H.
FIGURE 21.

HEAD LOSS CURVES
2.0 U.S. GPM PER SQ. FT.



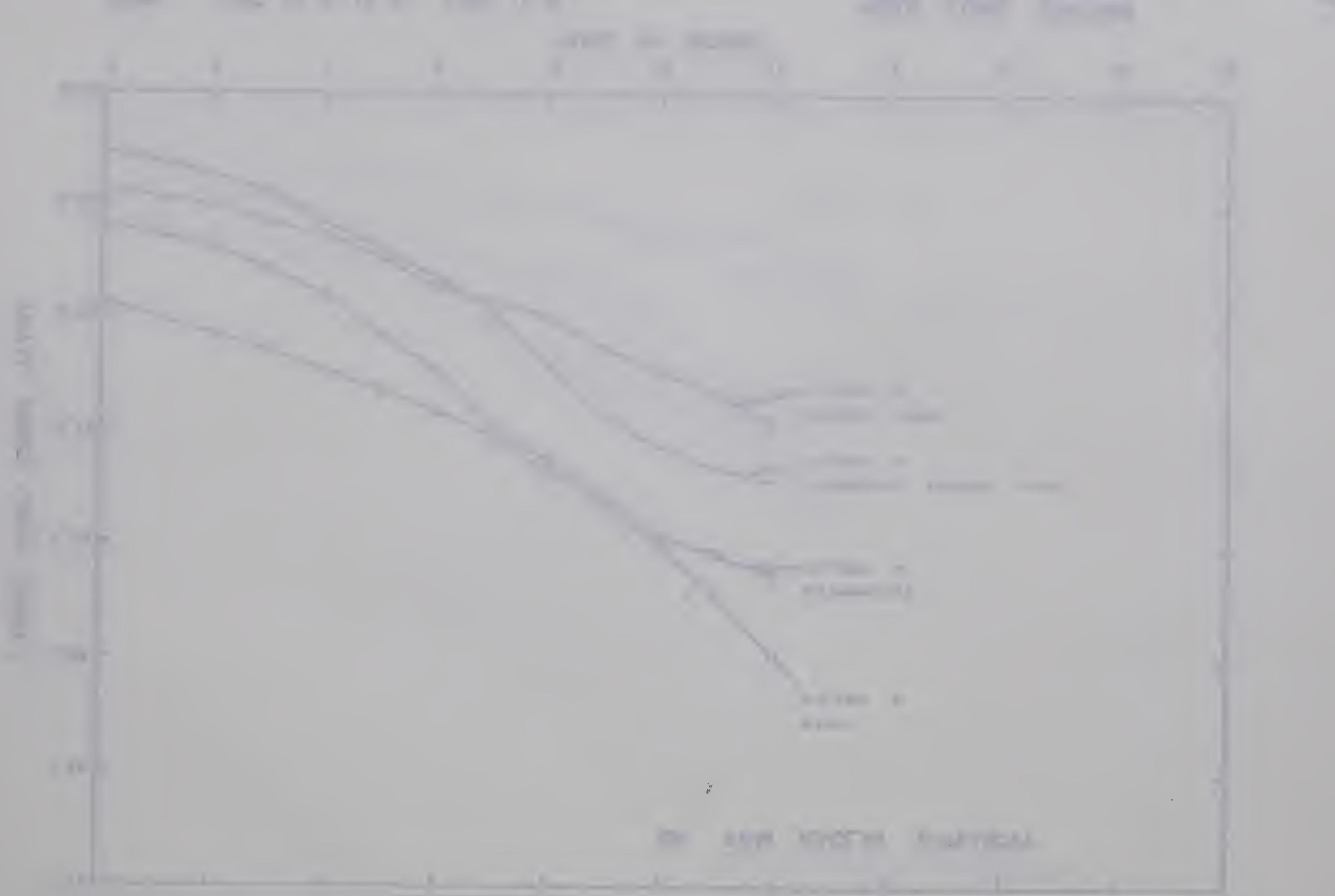


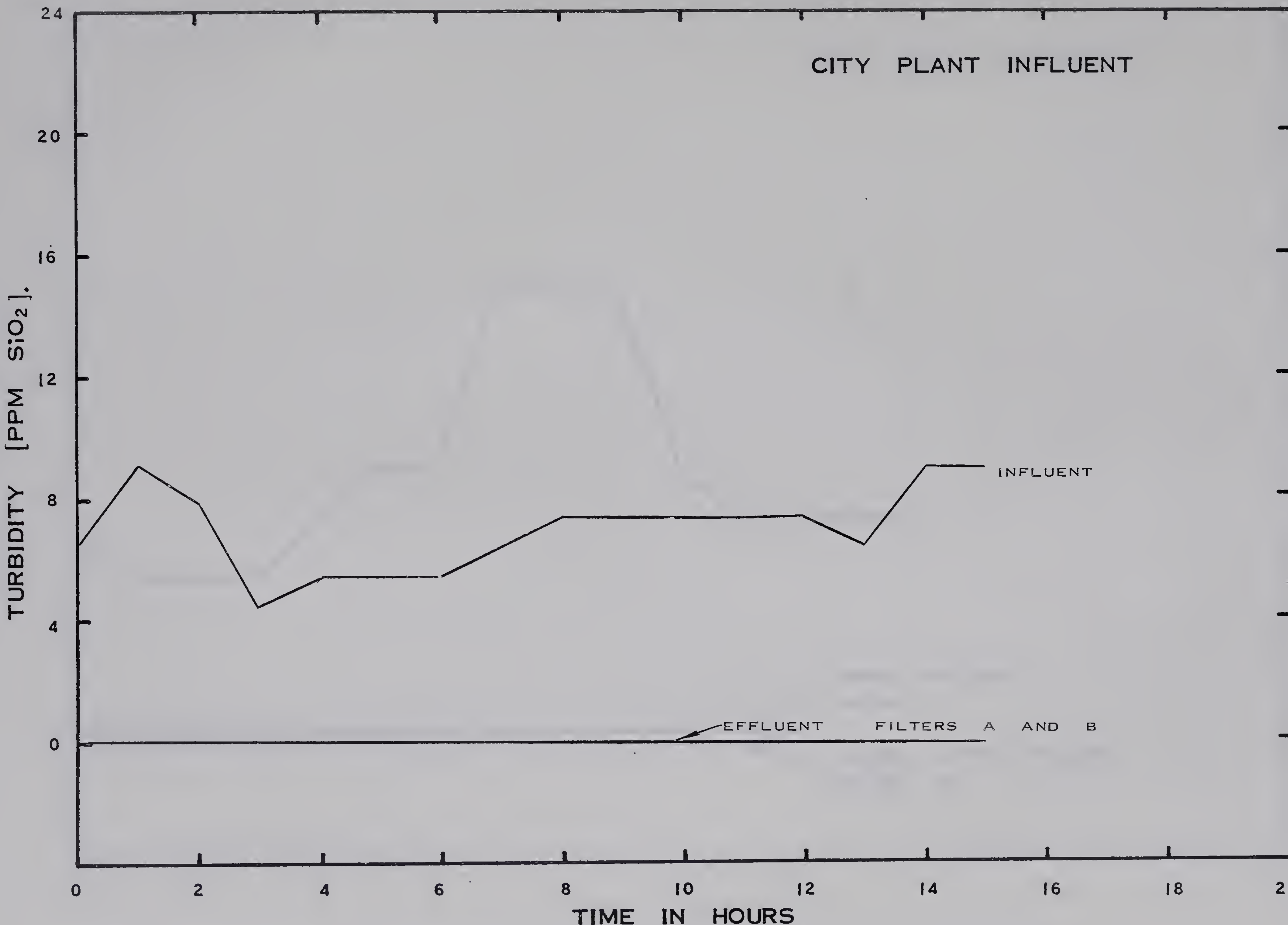
RUN 17E, 17 F, 17 G AND 17 H.

FIGURE 22.

HEAD LOSS CURVES

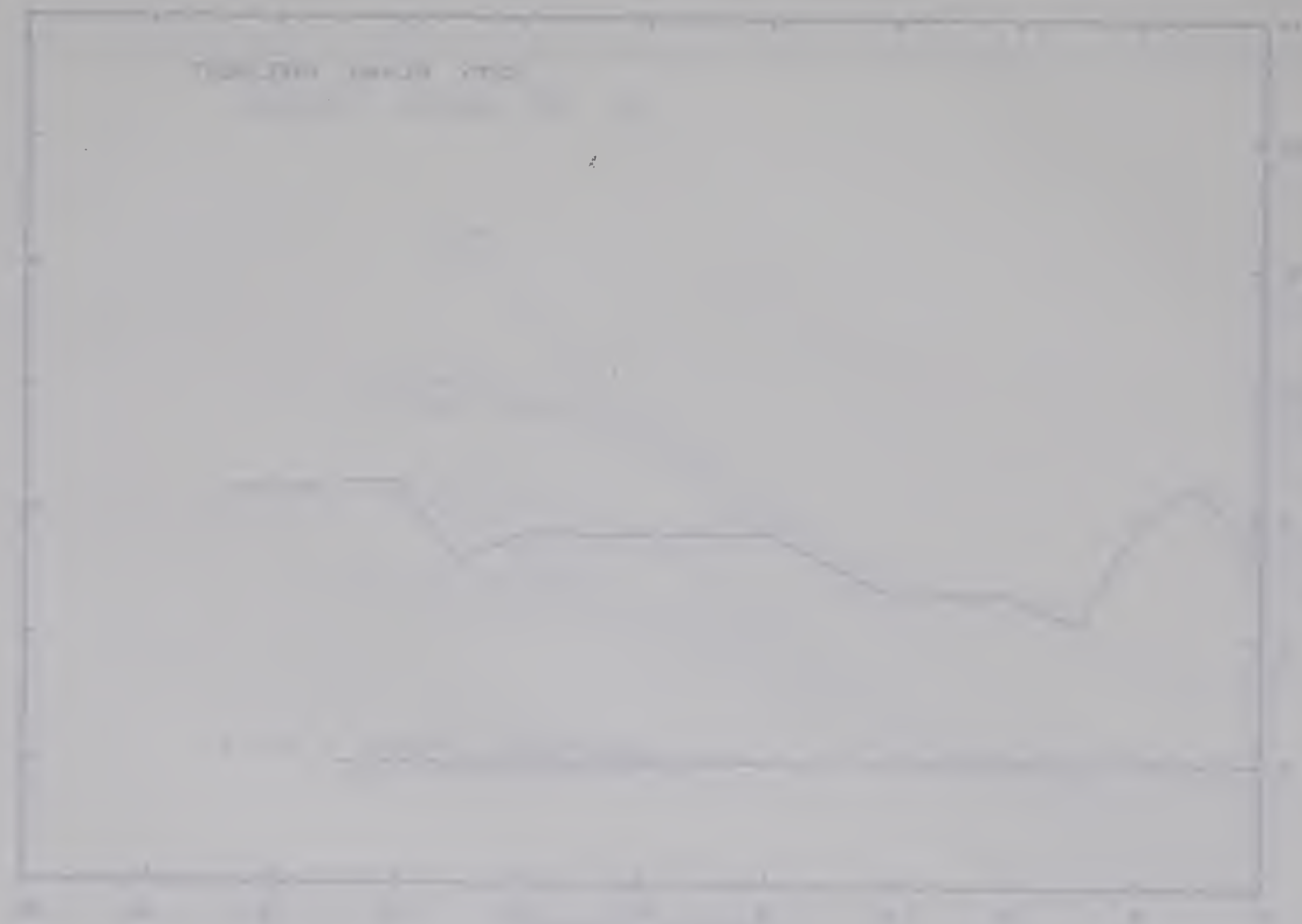
4.0 U.S. GPM PER SQ.FT.

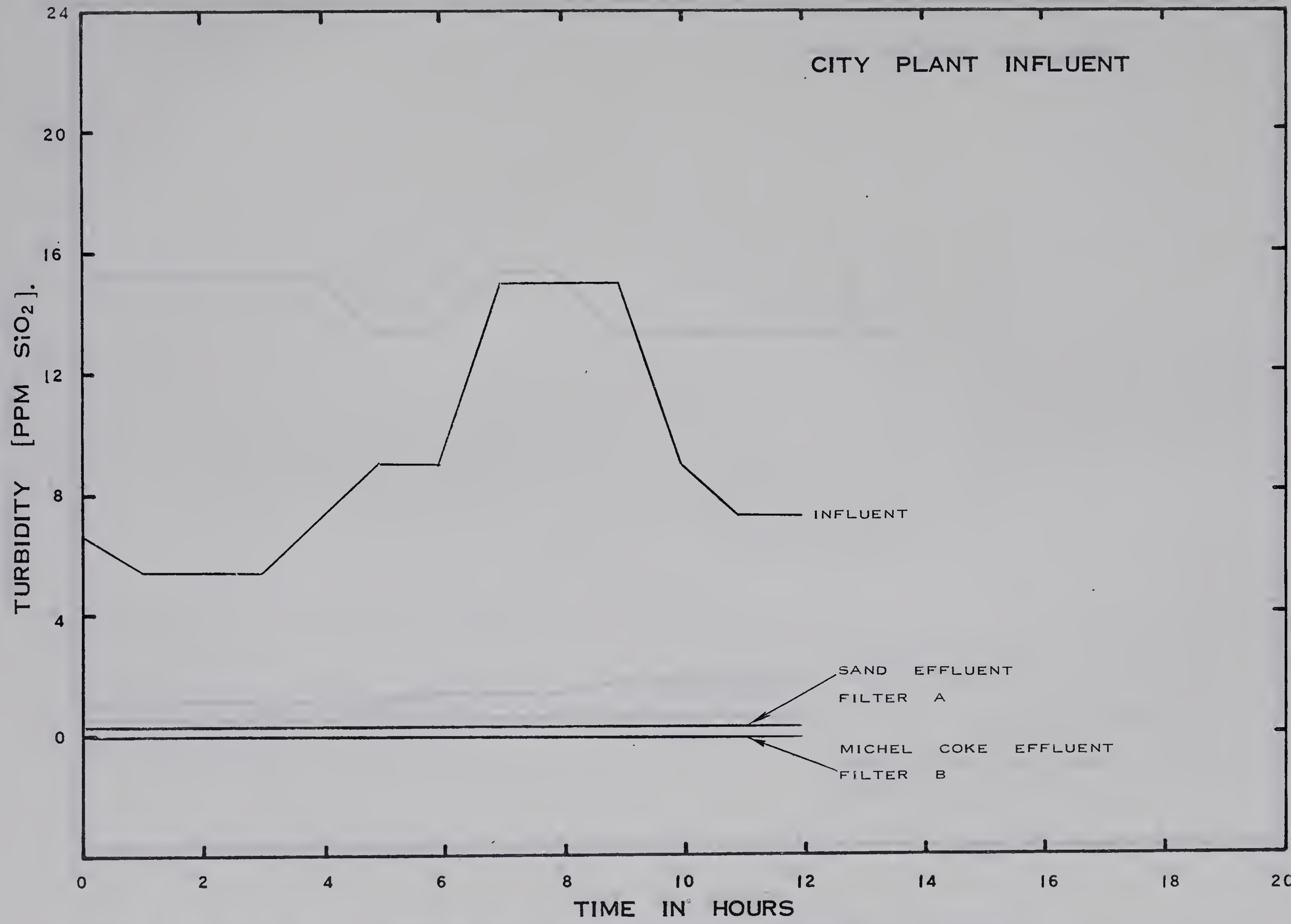




RUN I A AND I B. INFLUENT AND EFFLUENT TURBIDITY CURVES

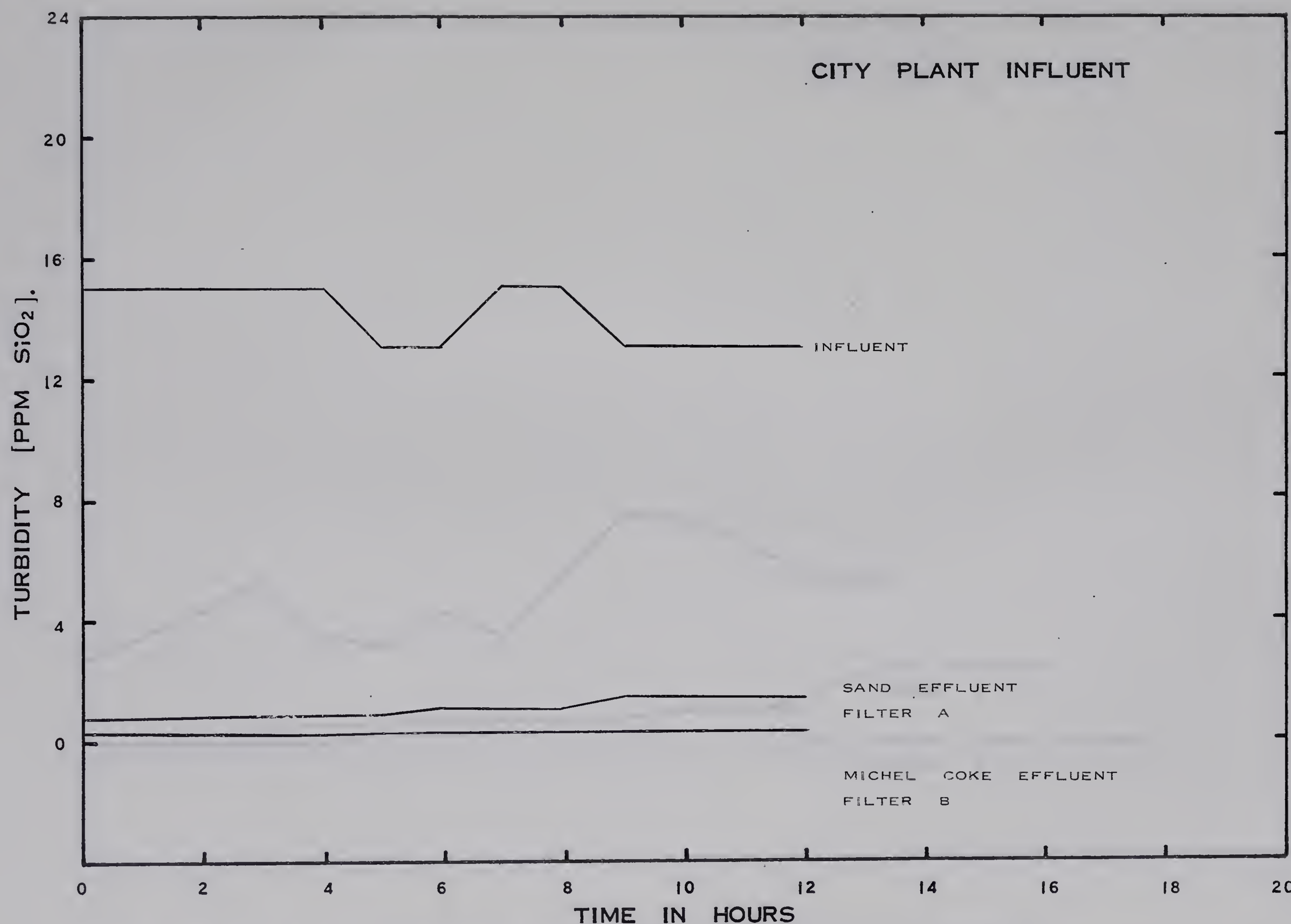
FIGURE 23. 2.4 U.S. GPM PER SQ. FT.





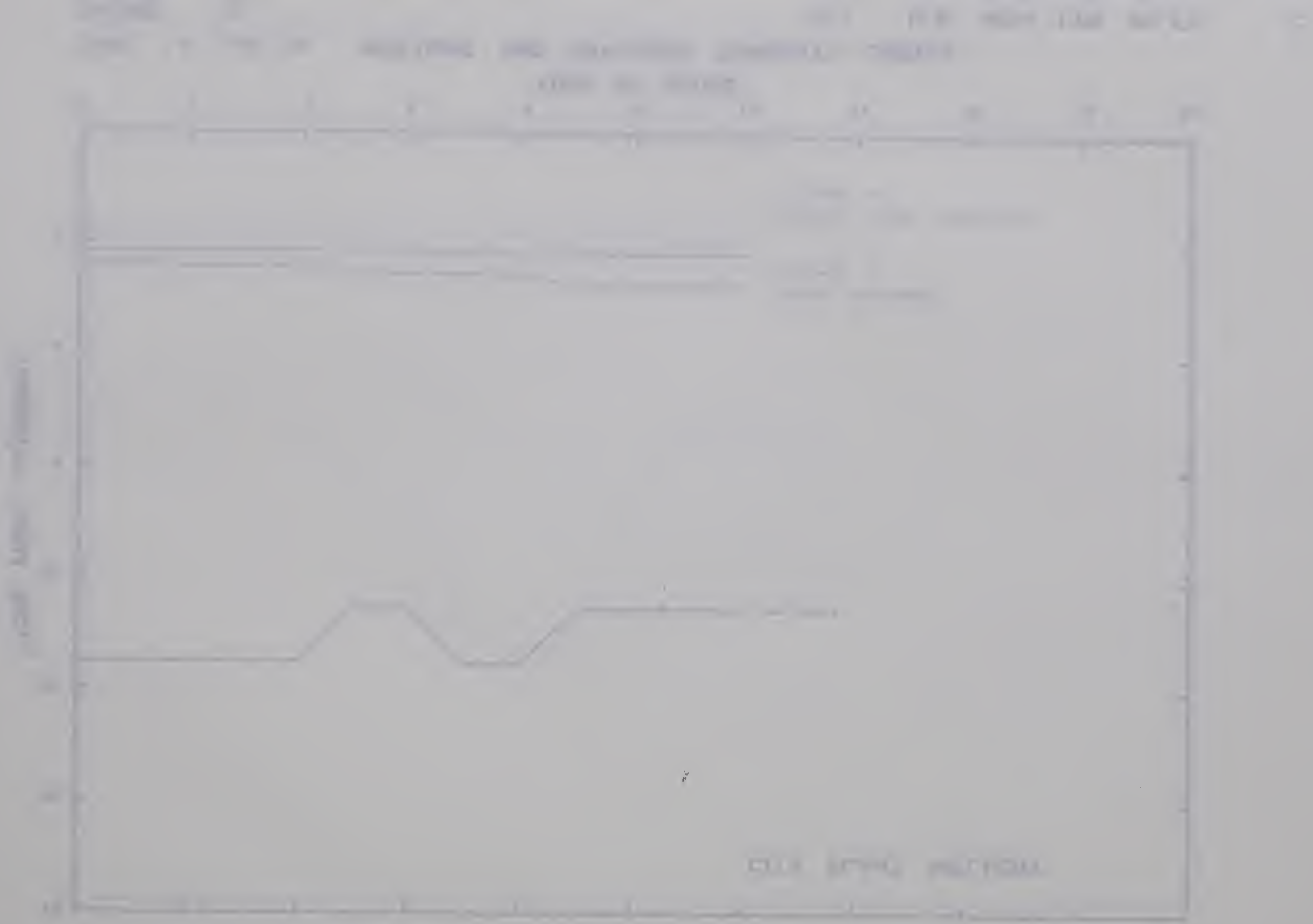
RUN 2 A AND 2 B. INFLUENT AND EFFLUENT TURBIDITY CURVES

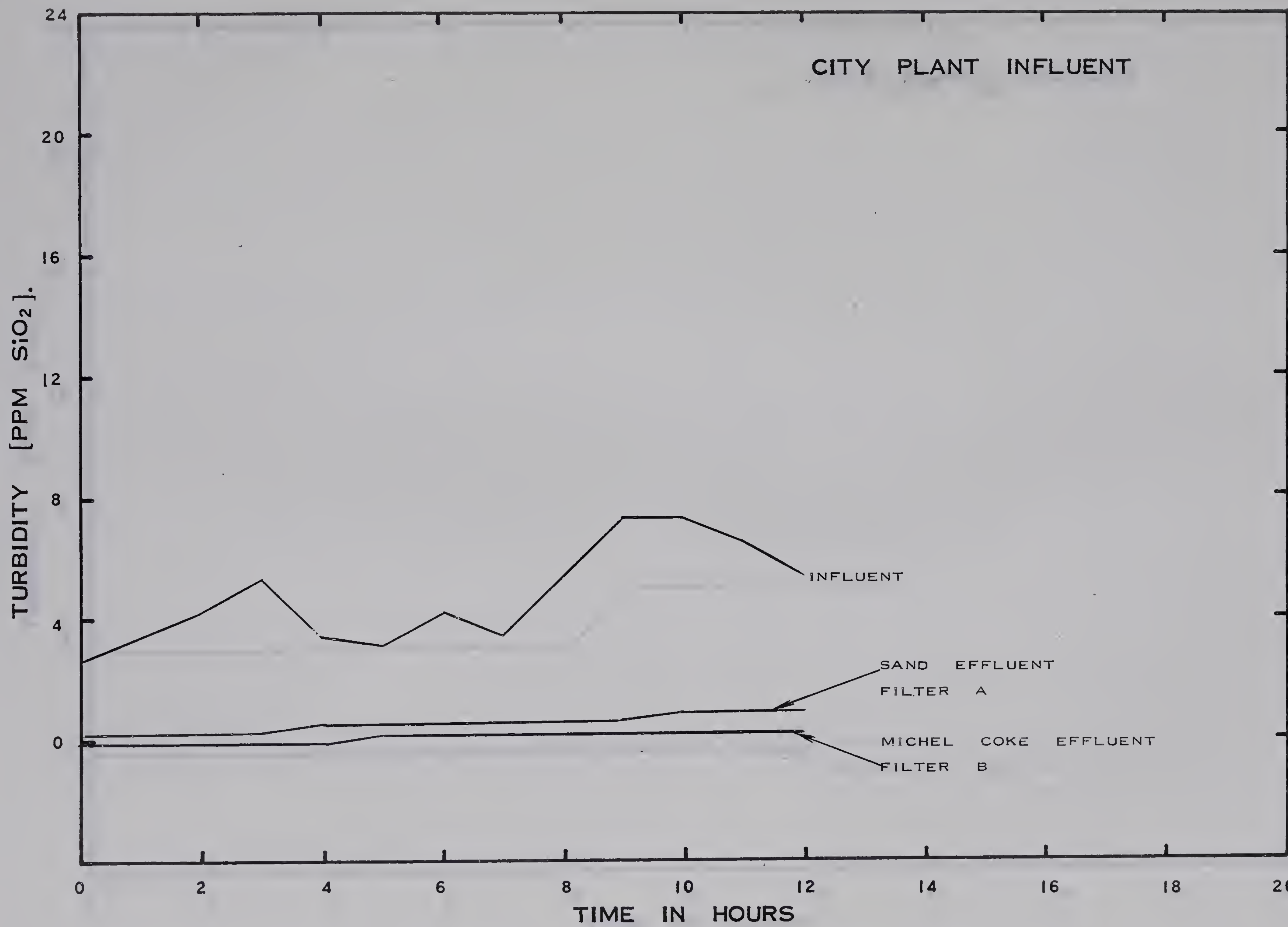
FIGURE 24. 5.0 U.S. GPM PER SQ. FT.



RUN 3 A AND 3B. INFLUENT AND EFFLUENT TURBIDITY CURVES

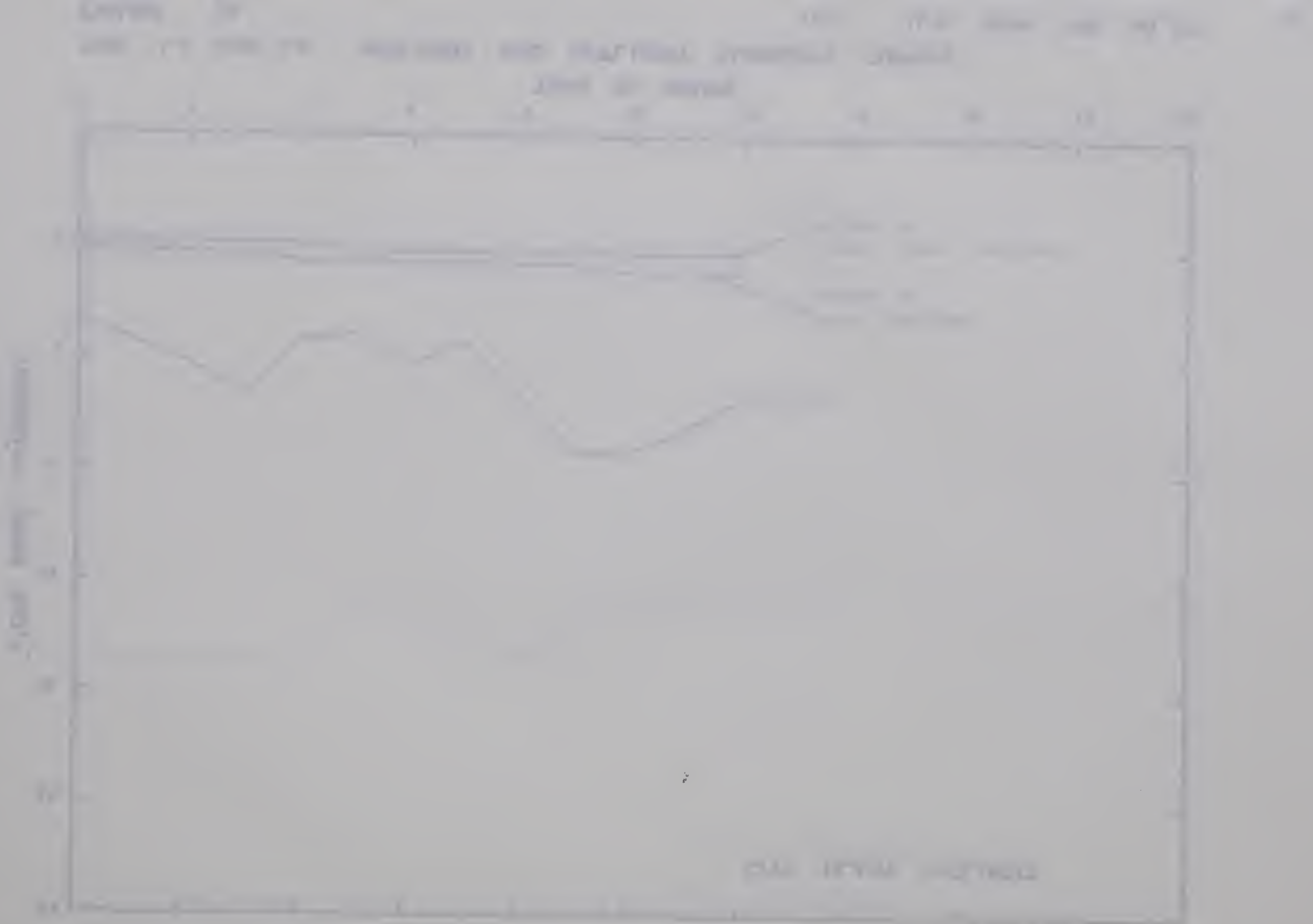
FIGURE 25. 10.0 U.S. GPM PER SQ. FT.





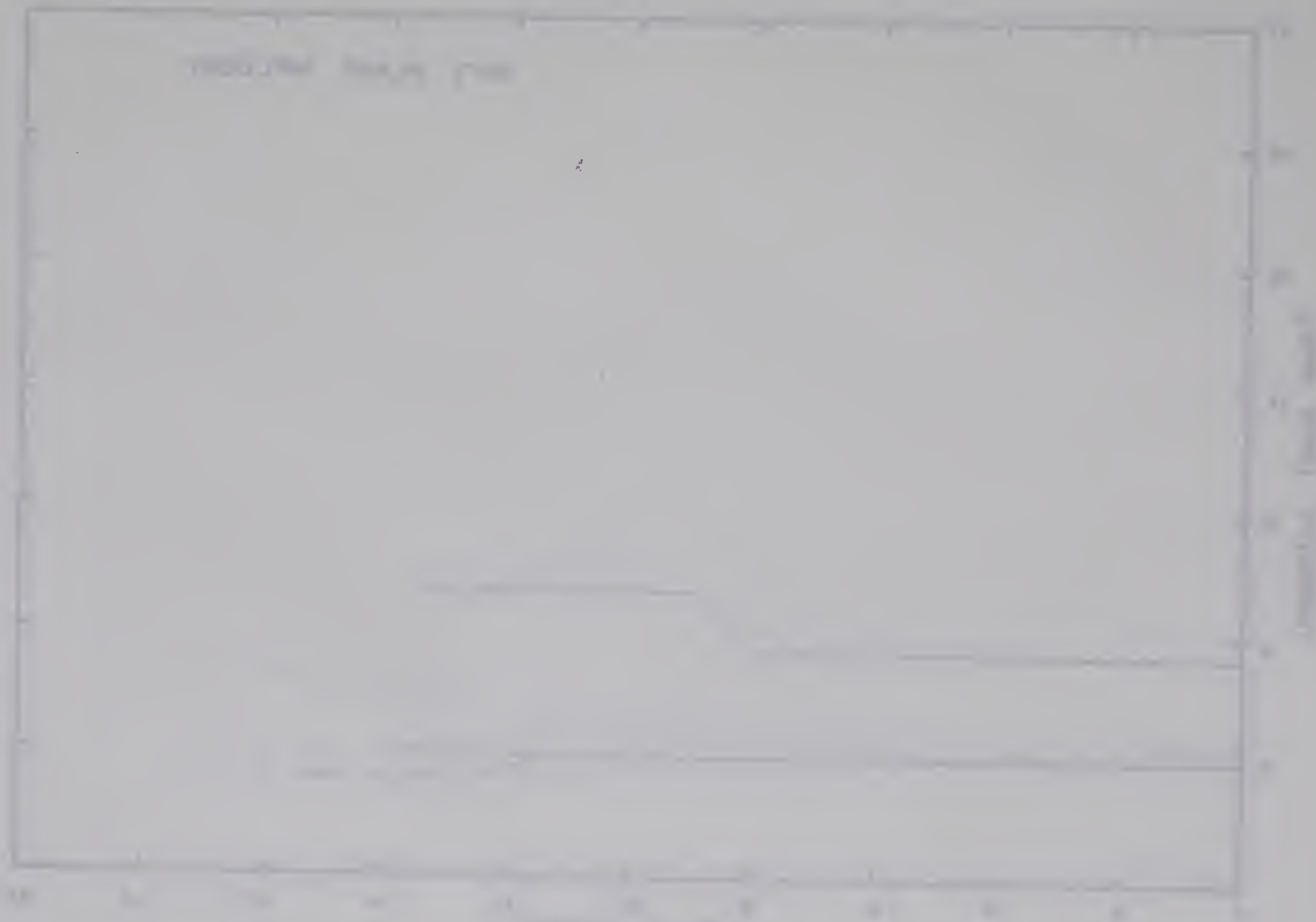
RUN 4 A AND 4 B. INFLUENT AND EFFLUENT TURBIDITY CURVES

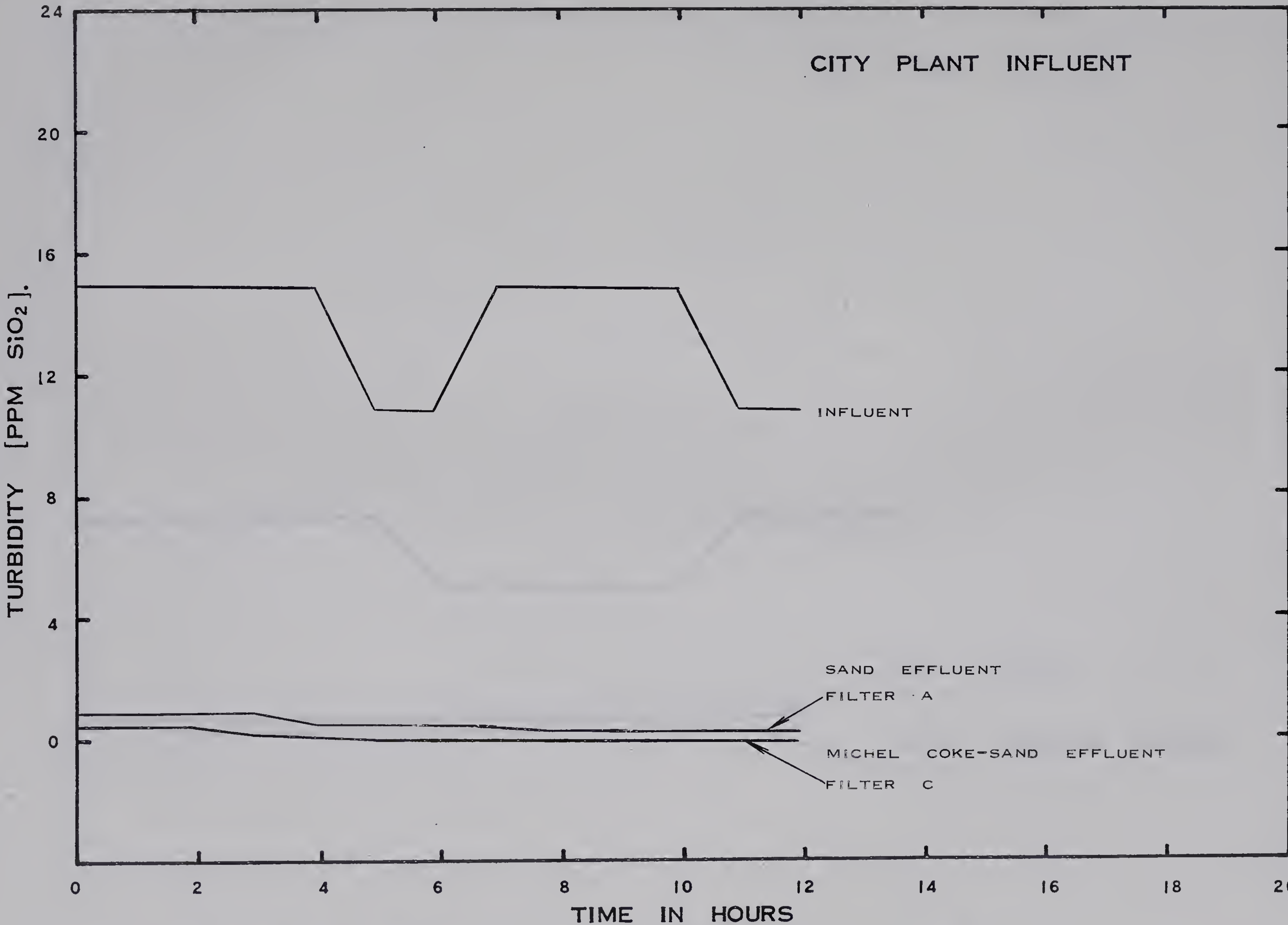
FIGURE 26. 12.0 U.S. GPM PER SQ. FT.



RUN 5 A AND 5 C. INFLUENT AND EFFLUENT TURBIDITY CURVES

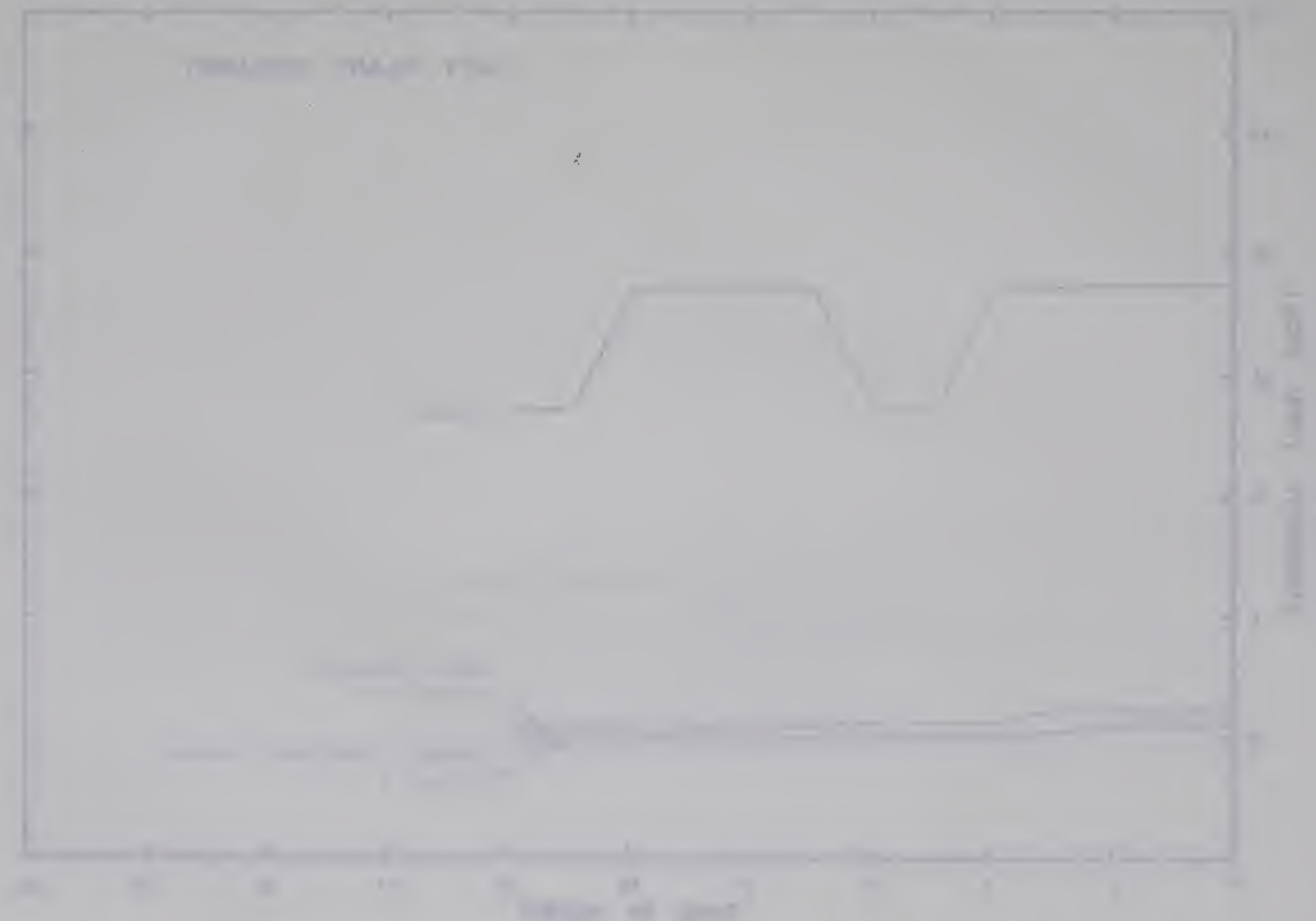
FIGURE 27. 3.0 U.S. GPM PER SQ. FT.

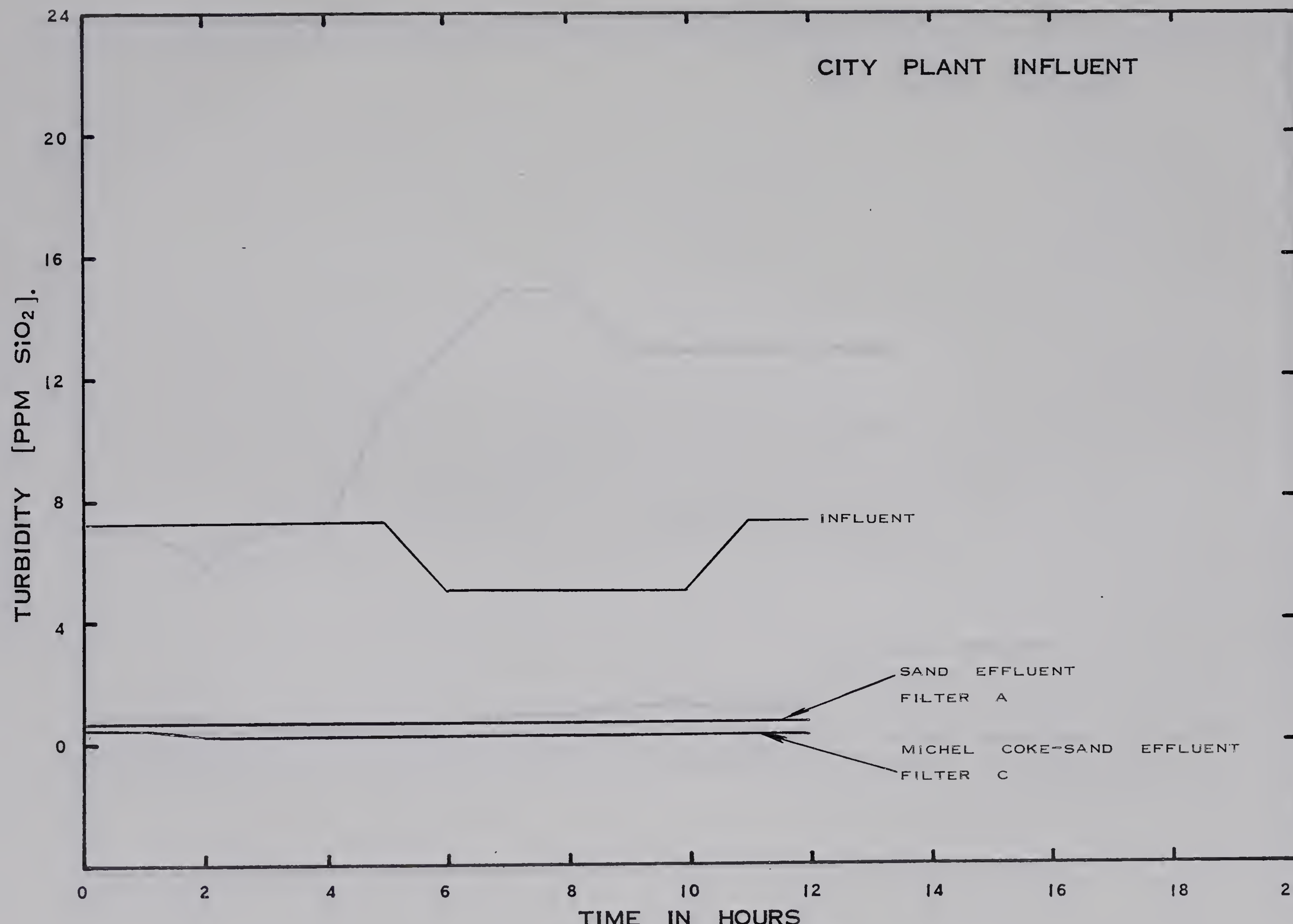




RUN 6 A AND 6 C. INFLUENT AND EFFLUENT TURBIDITY CURVES

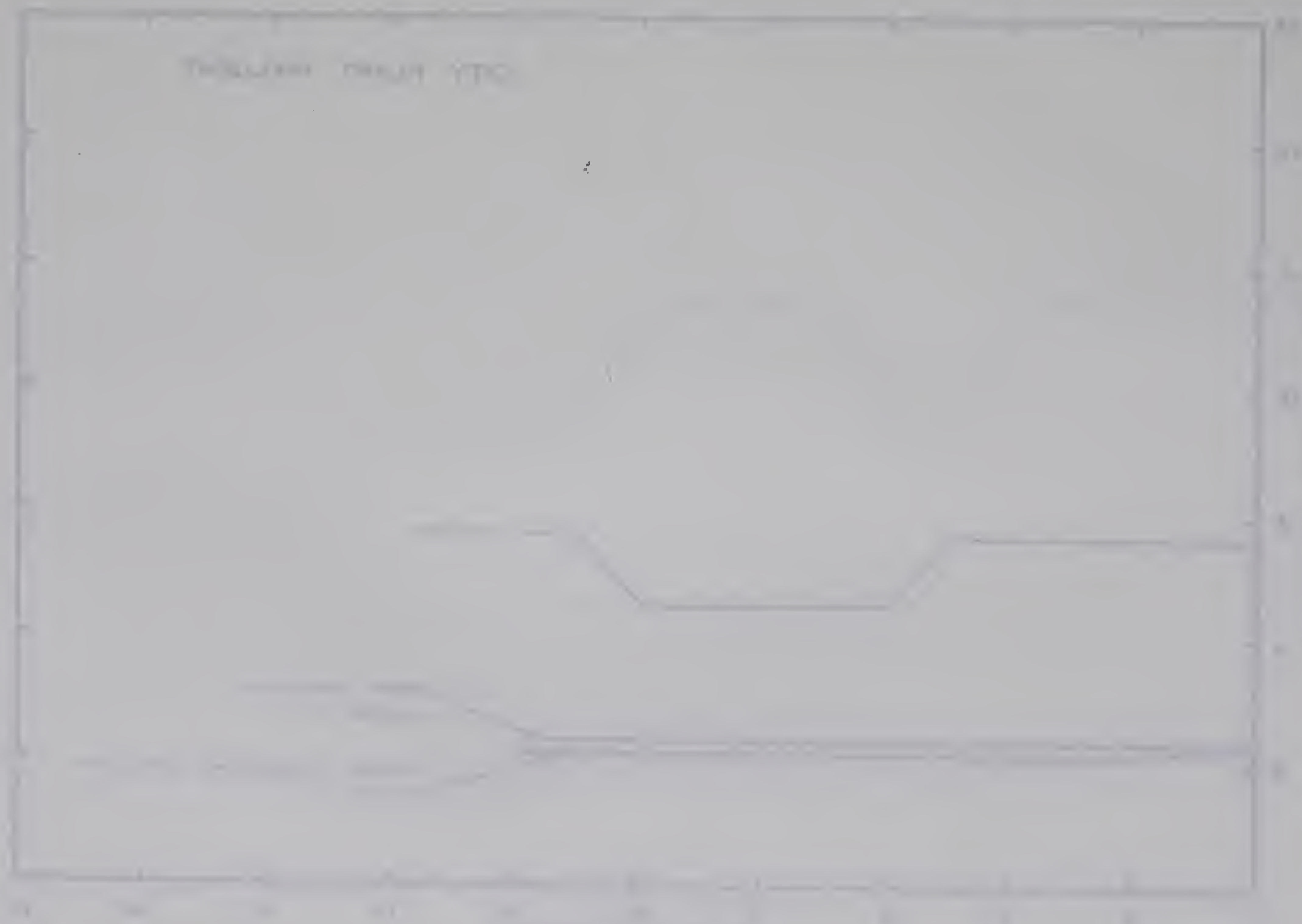
FIGURE 28. 5.0 U.S. GPM PER SQ. FT.

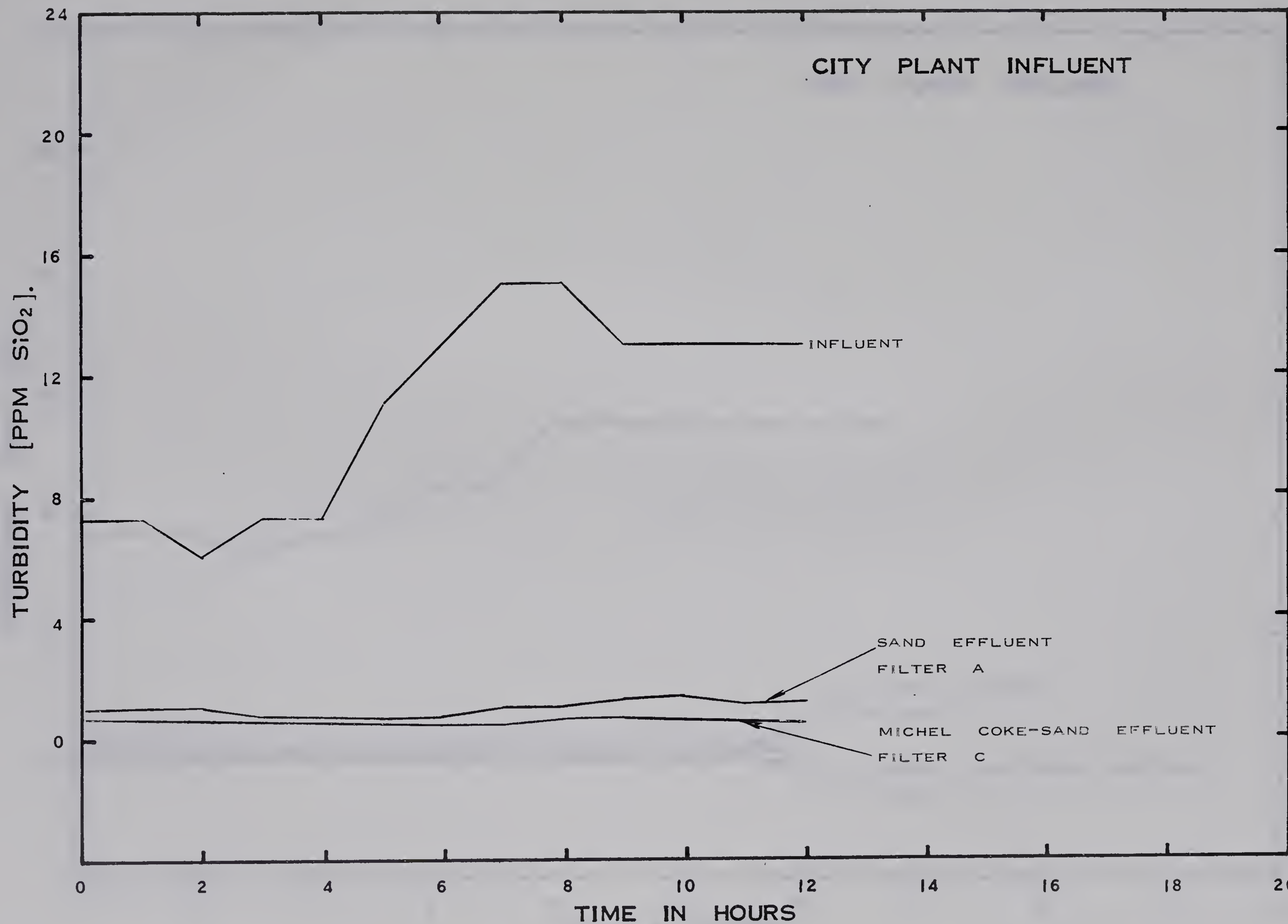




RUN 7 A AND 7 C. INFLUENT AND EFFLUENT TURBIDITY CURVES

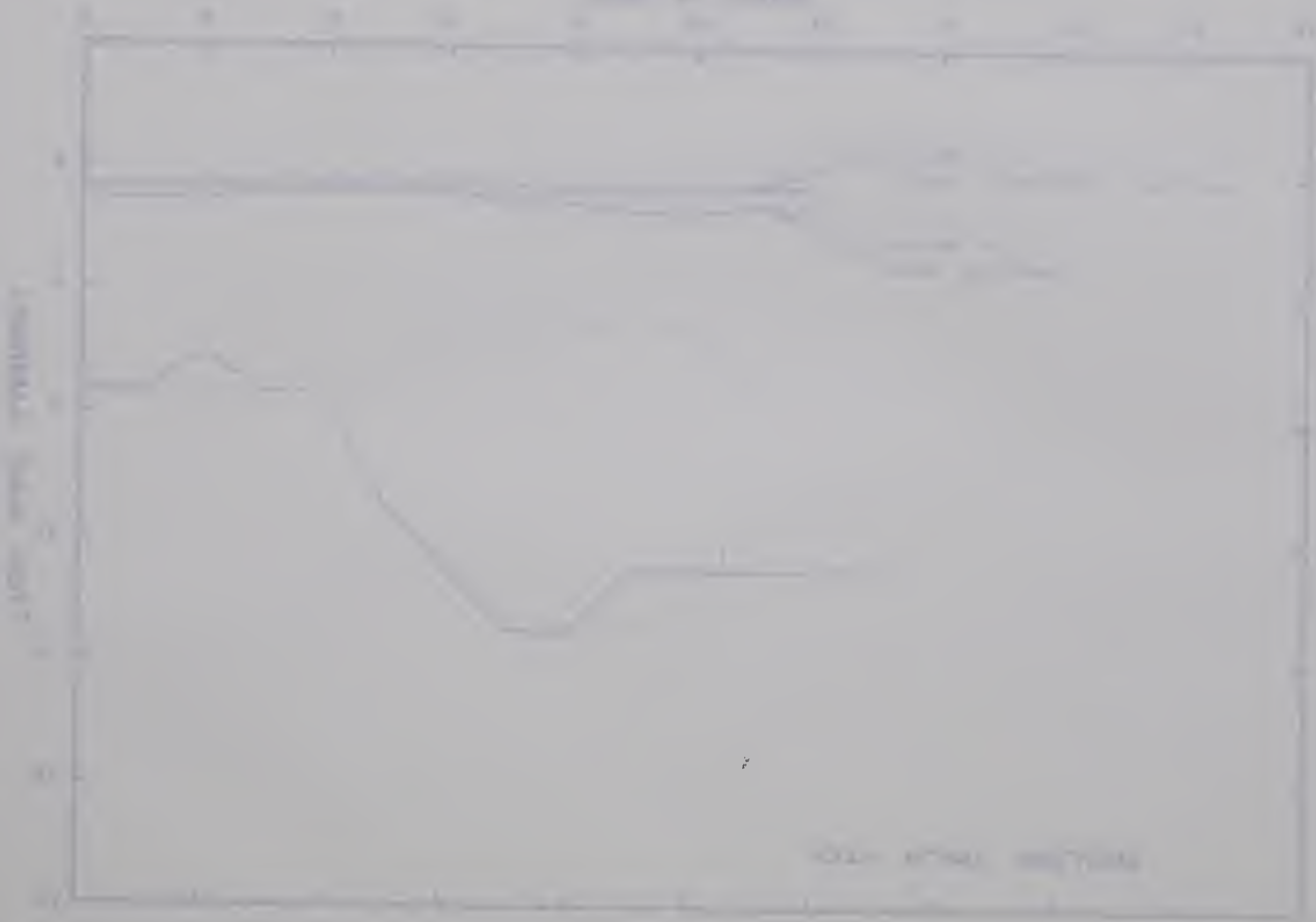
FIGURE 29. 8.25 U.S. GPM PER SQ. FT.

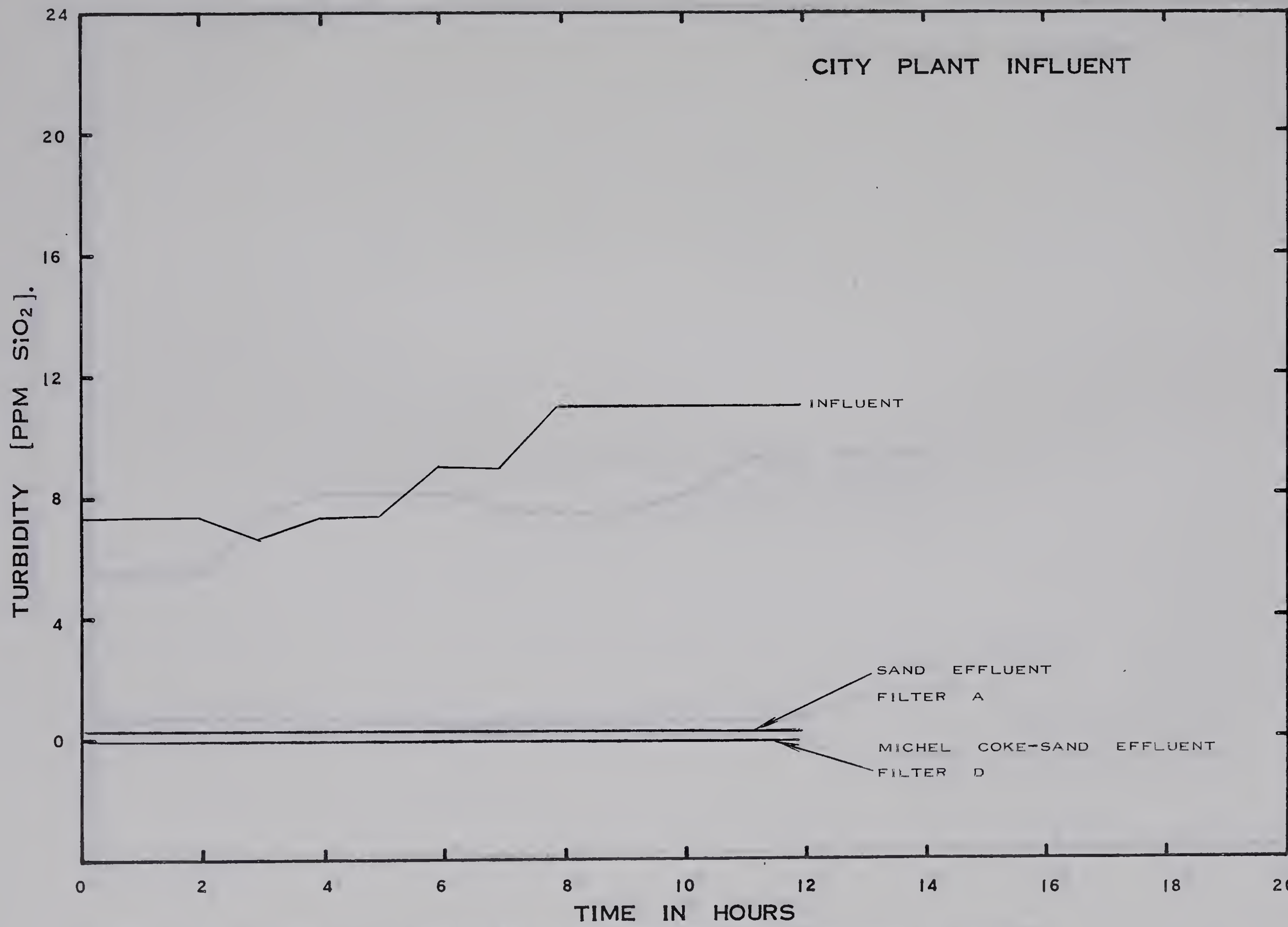




RUN 8 A AND 8 C. INFLUENT AND EFFLUENT TURBIDITY CURVES

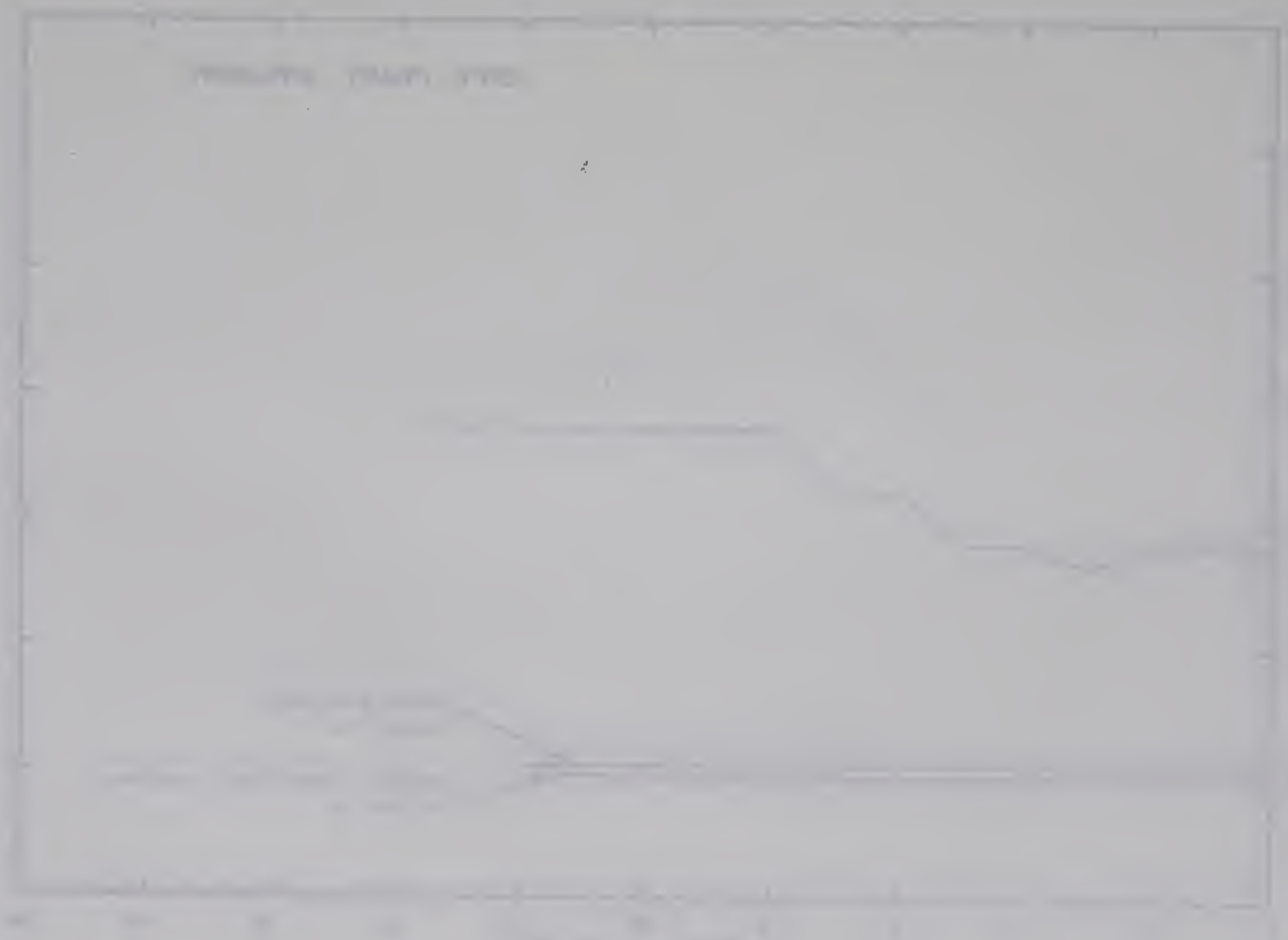
FIGURE 30. 12.0 U.S. GPM PER SQ. FT.

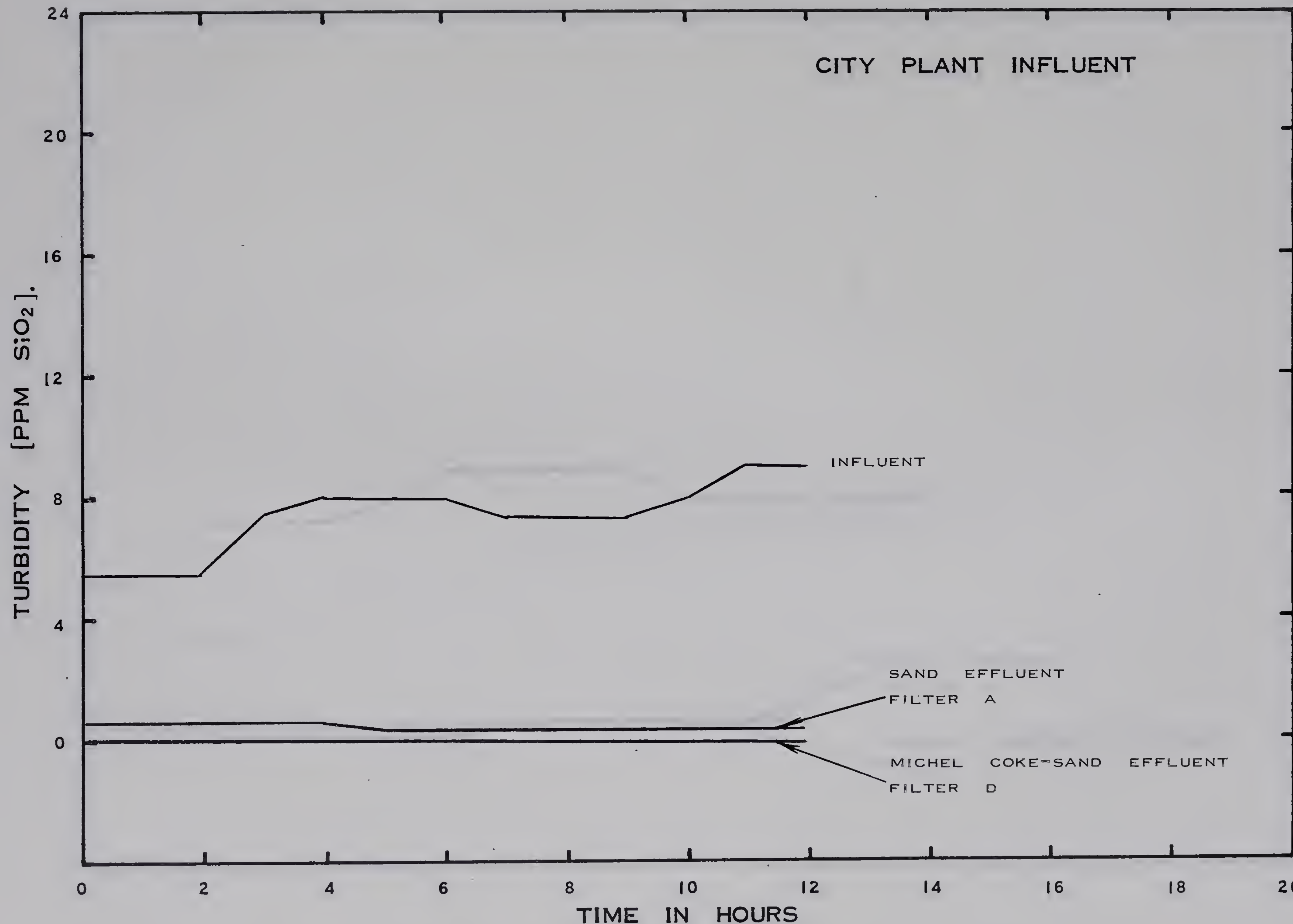




RUN 9 A AND 9 D. INFLUENT AND EFFLUENT TURBIDITY CURVES

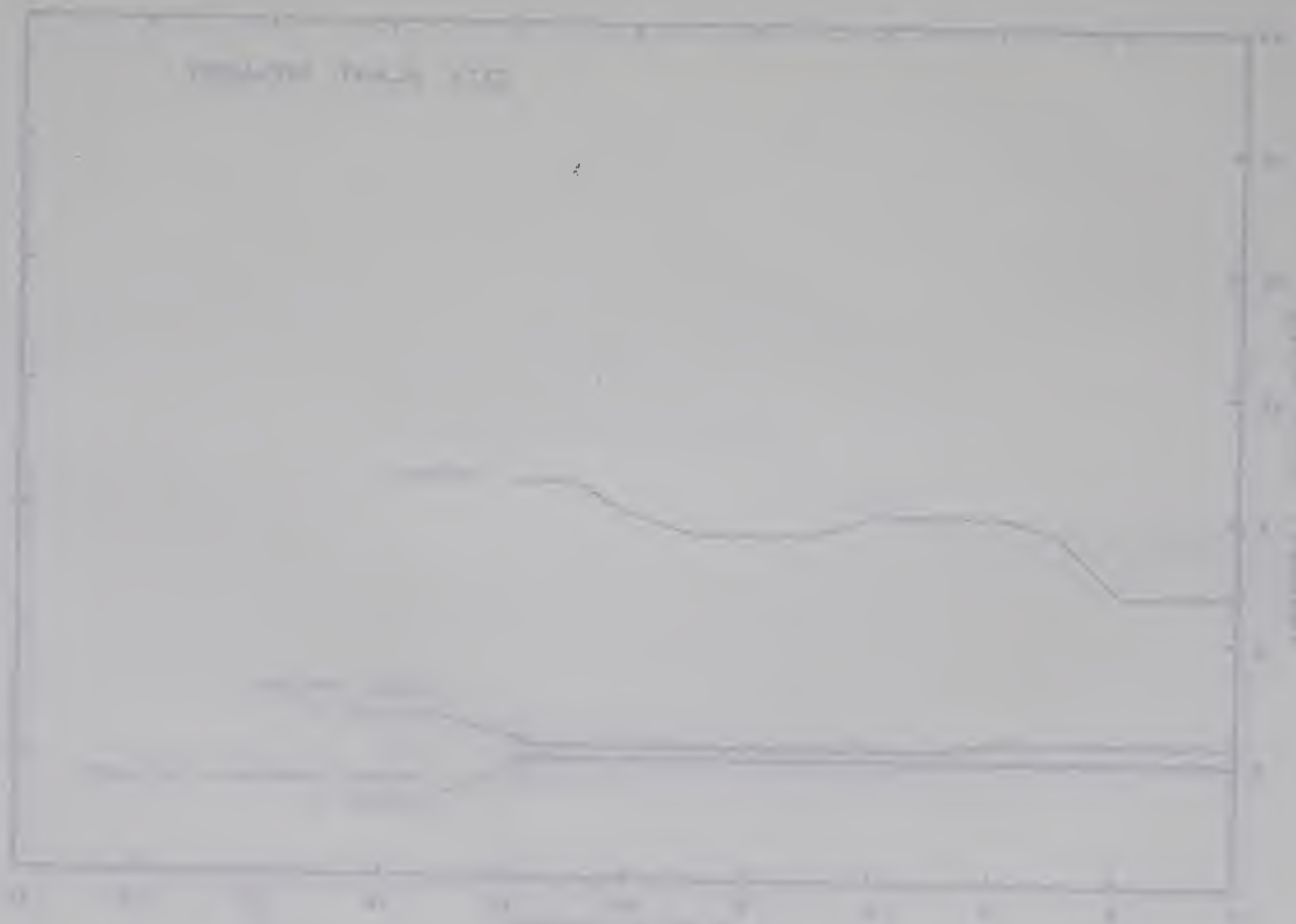
FIGURE 31. 4.0 U.S. GPM PER SQ. FT.

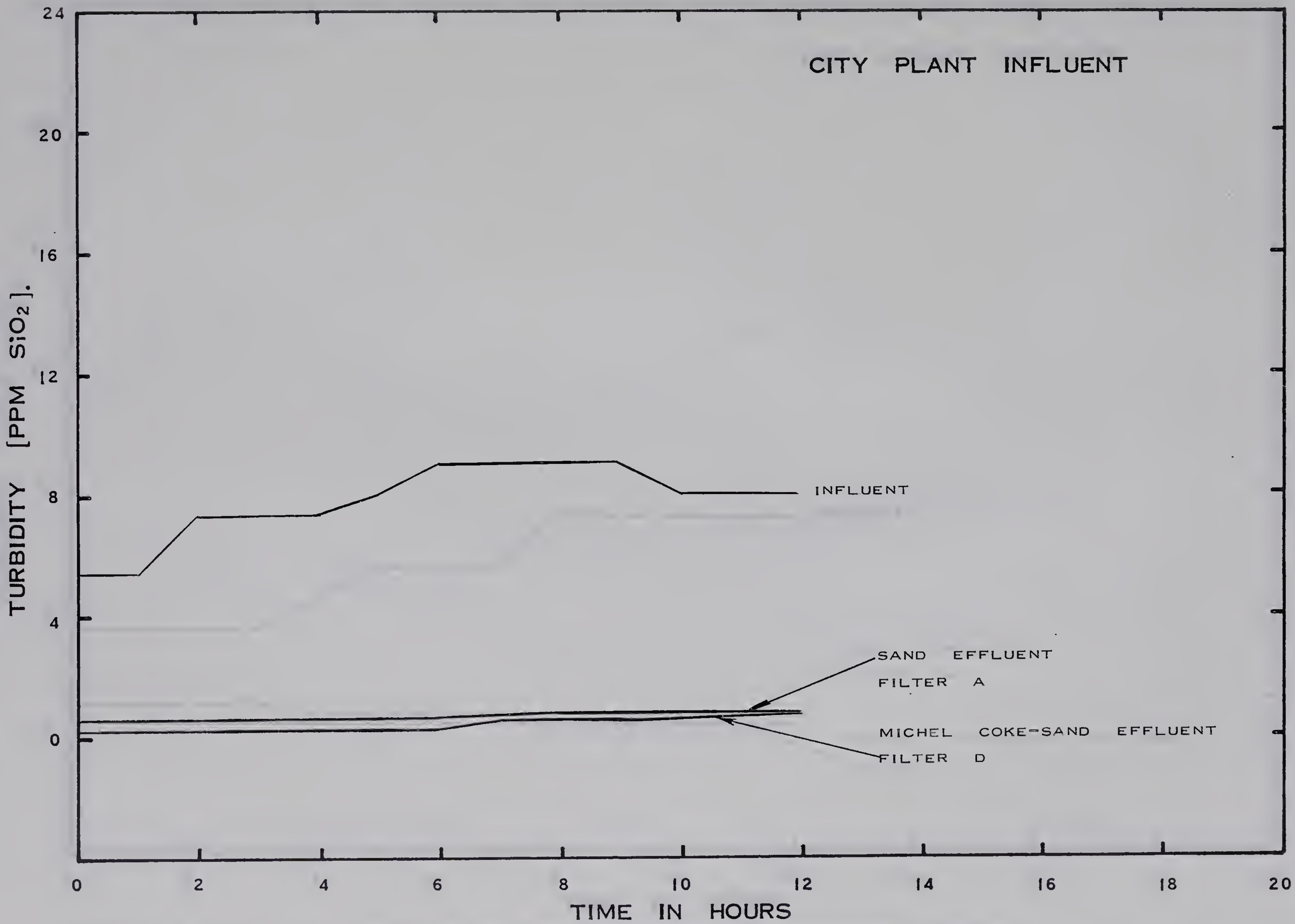




RUN 10 A AND 10 D. INFLUENT AND EFFLUENT TURBIDITY CURVES

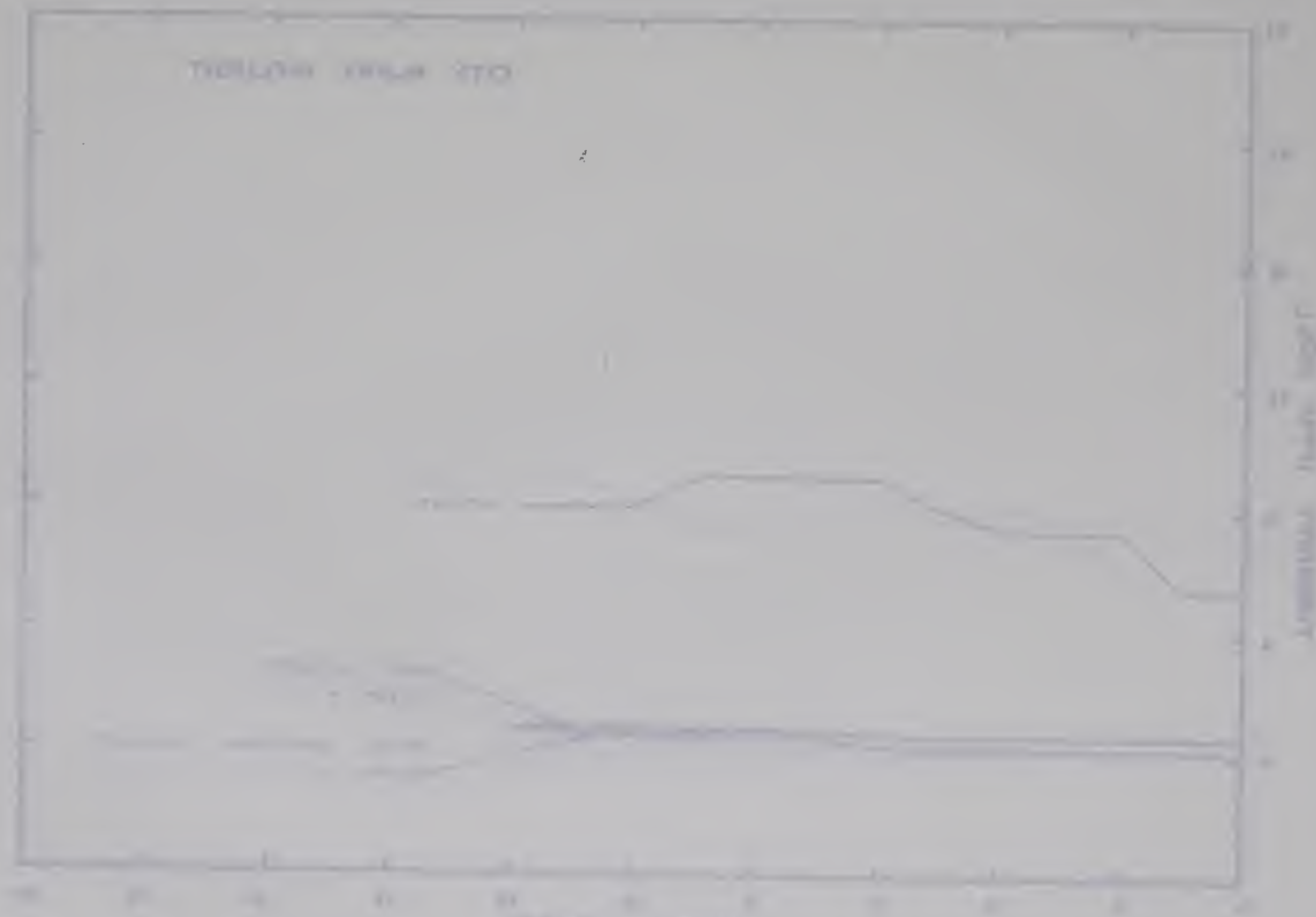
FIGURE 32. 5.0 U.S. GPM PER SQ. FT.

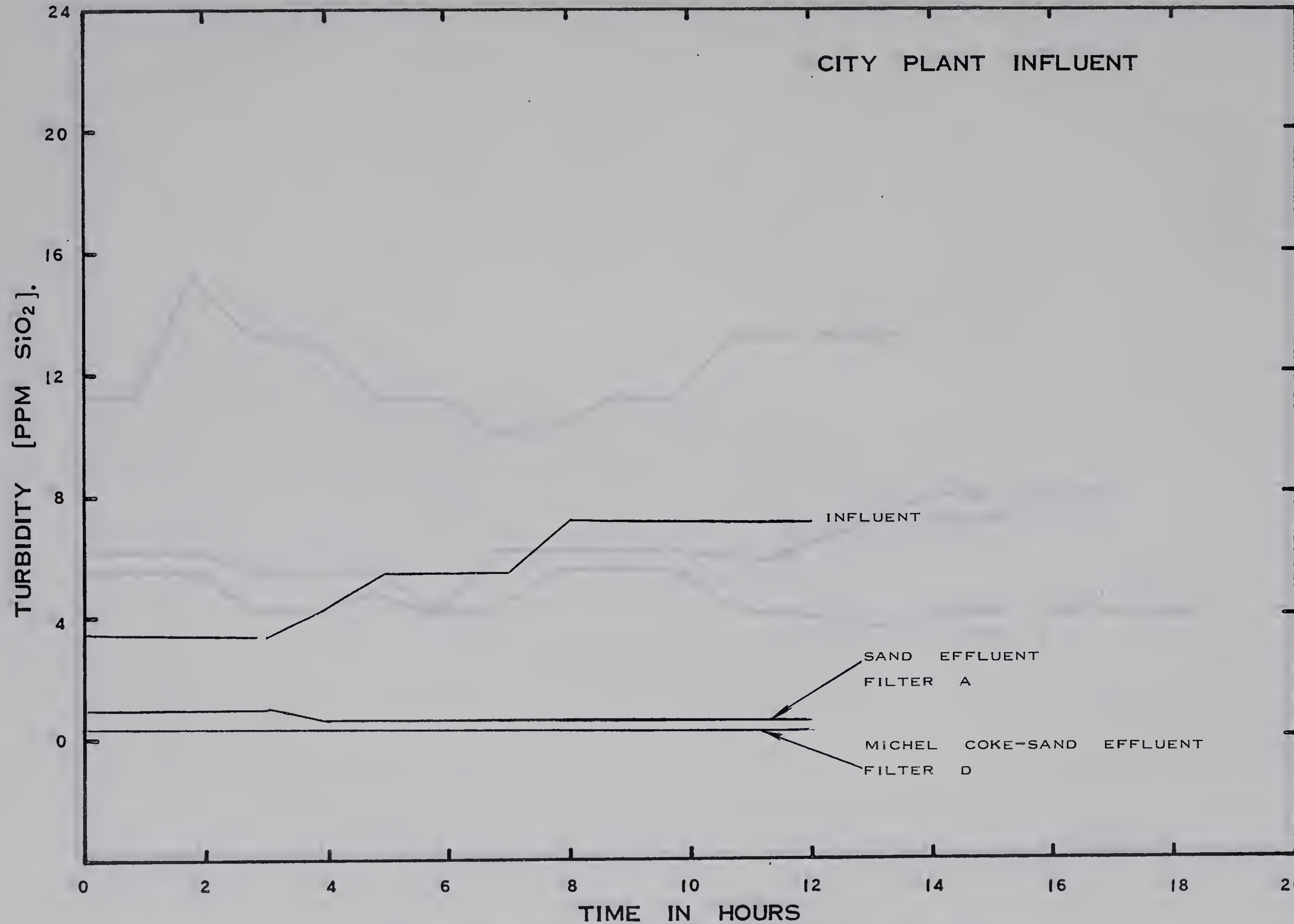




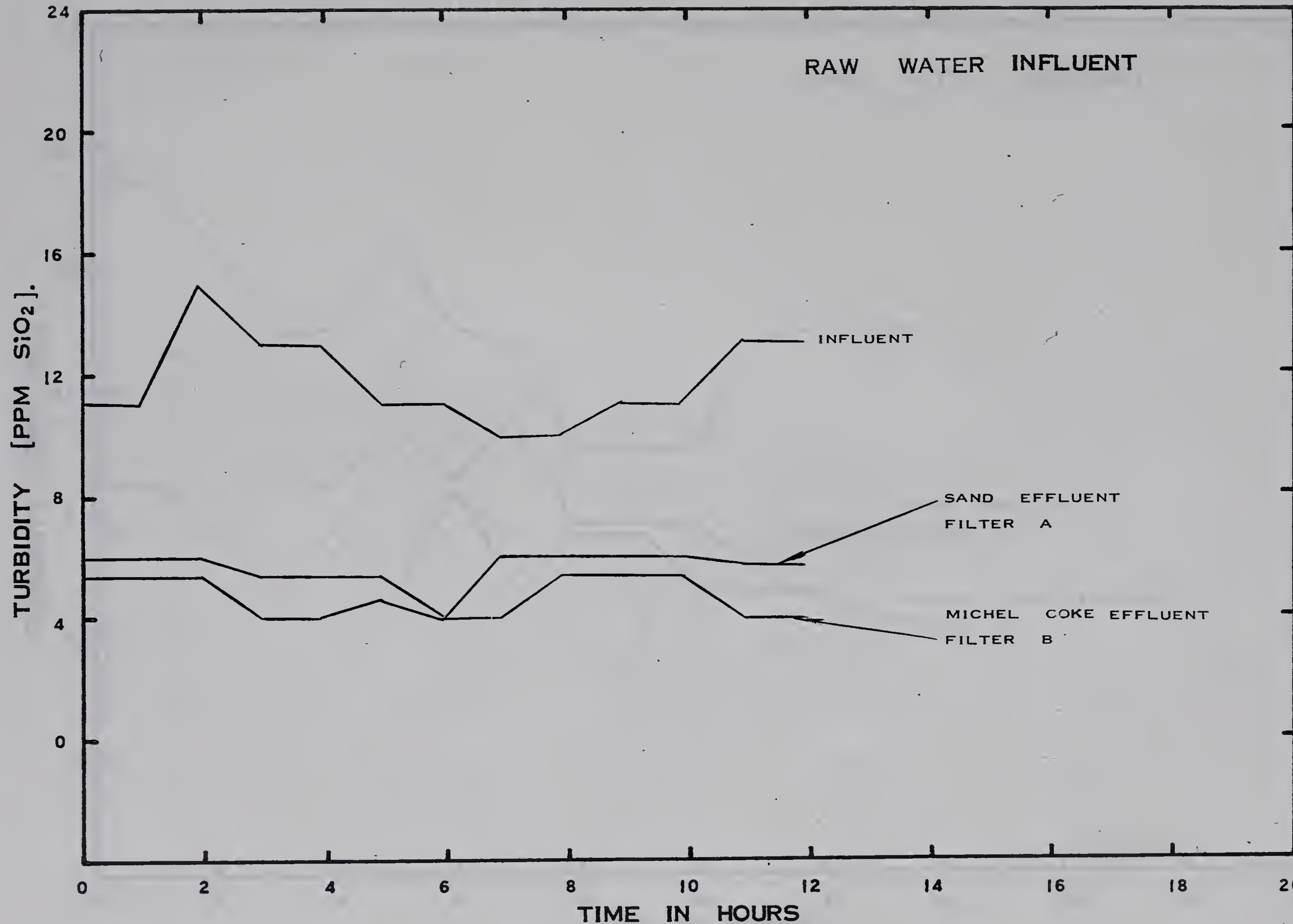
RUN II A AND II D. INFLUENT AND EFFLUENT TURBIDITY CURVES

FIGURE 33. 8.25 U.S. GPM PER SQ. FT.



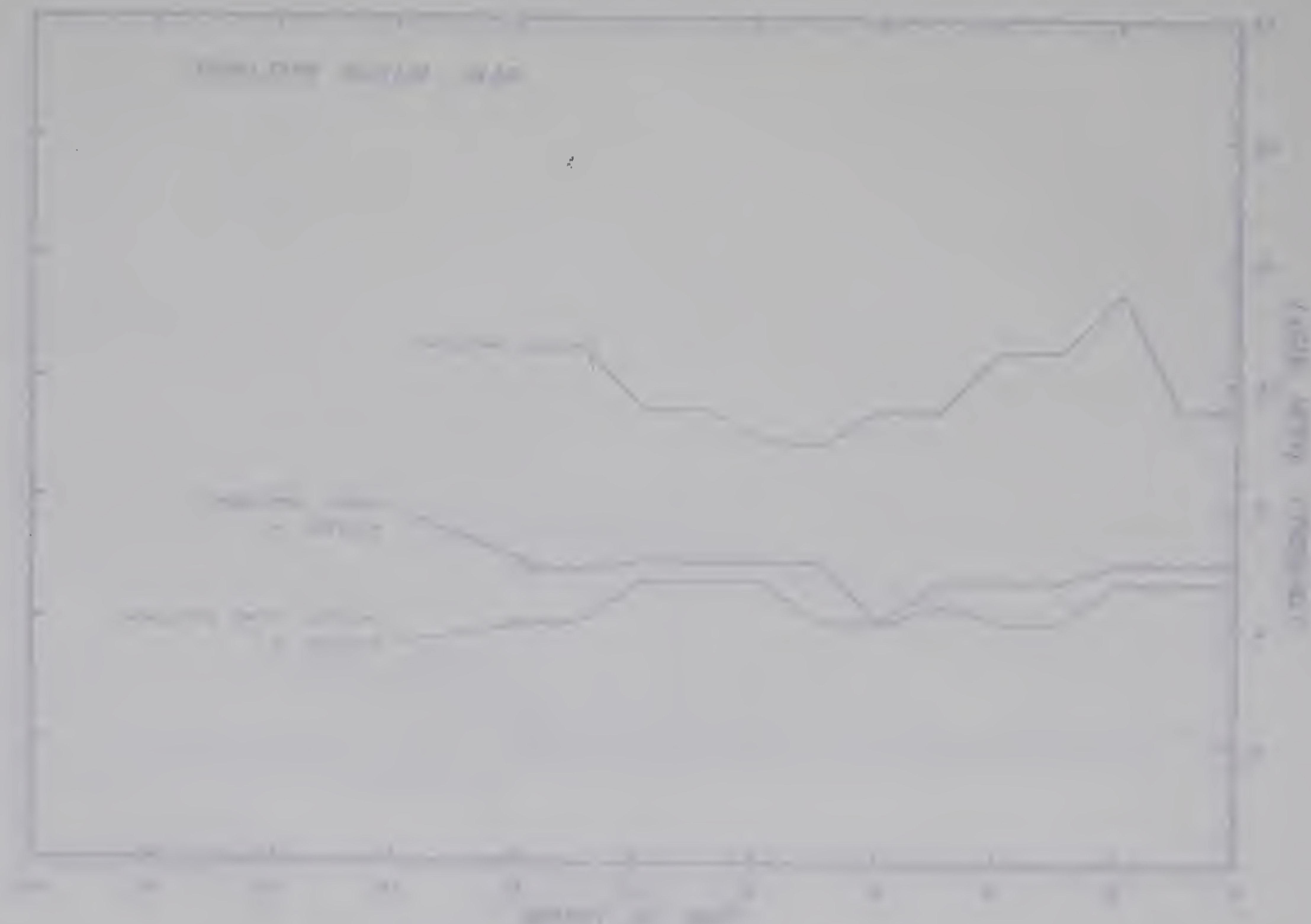


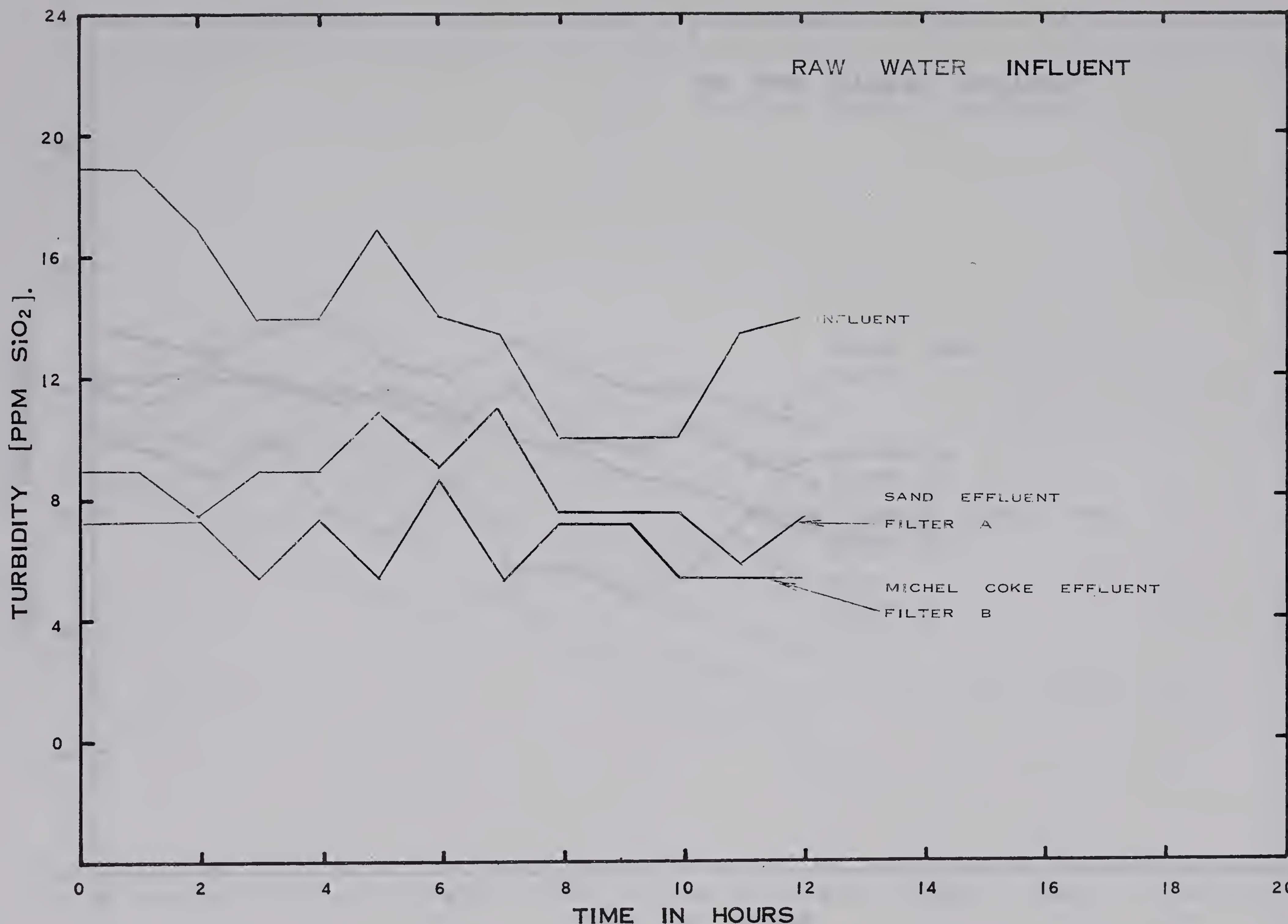
RUN 12 A AND 12 D. INFLUENT AND EFFLUENT TURBIDITY CURVES
FIGURE 34. 12.0 U.S. GPM PER SQ. FT.



RUN 14 A AND 14 B. INFLUENT AND EFFLUENT TURBIDITY CURVES

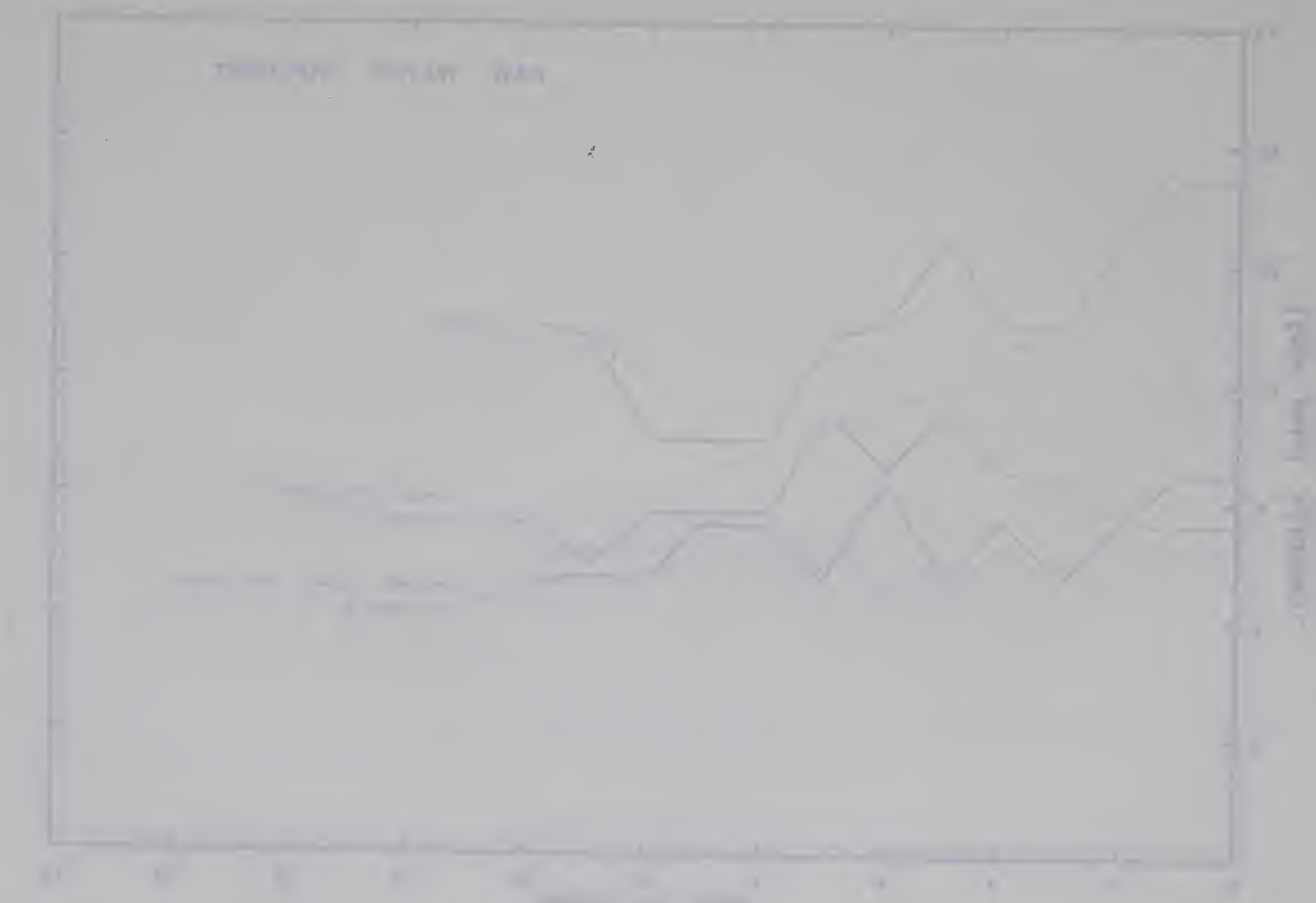
FIGURE 35. 2.4 U.S. GPM PER SQ. FT.

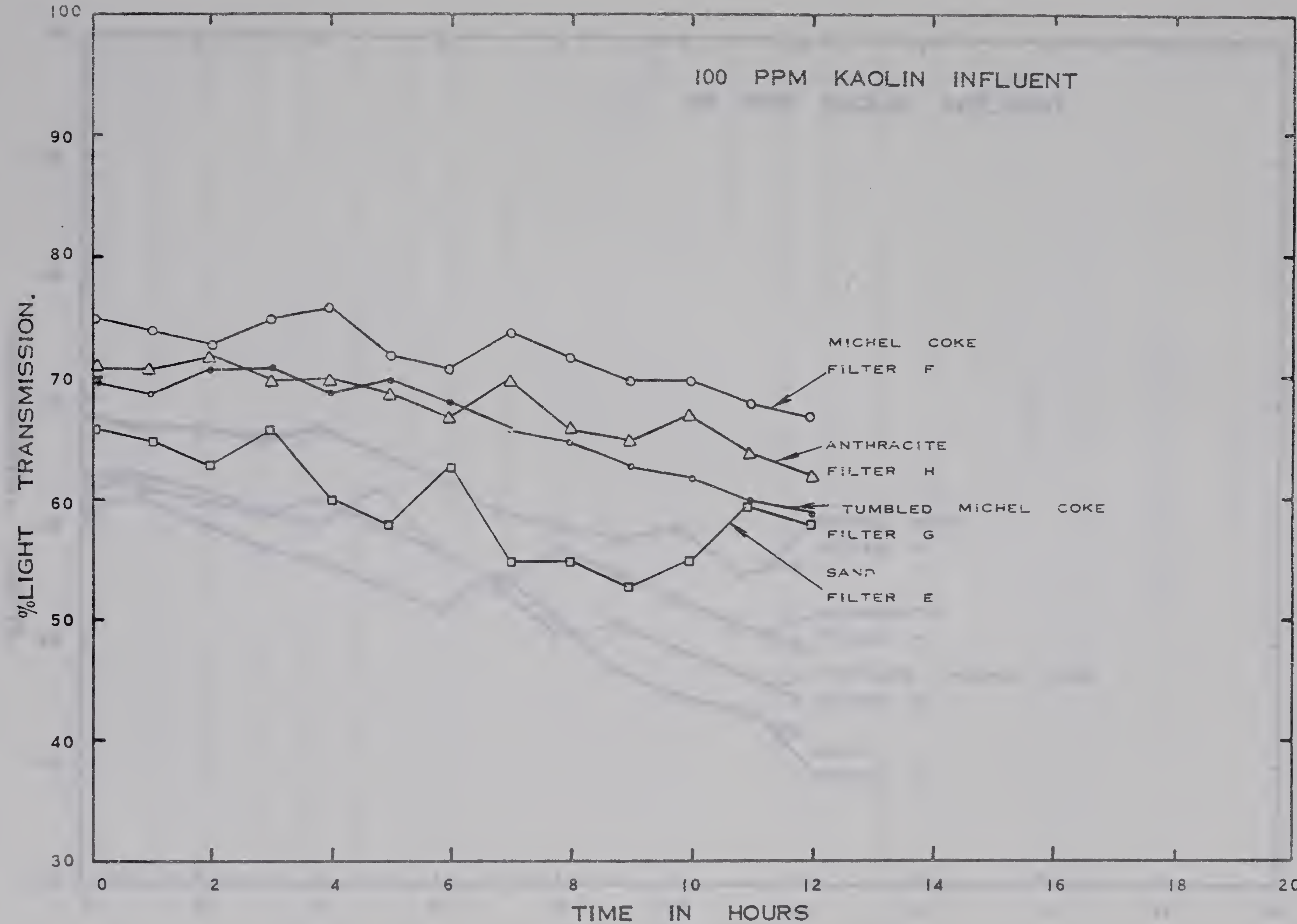




RUN 15 A AND 15 B. INFLUENT AND EFFLUENT TURBIDITY CURVES

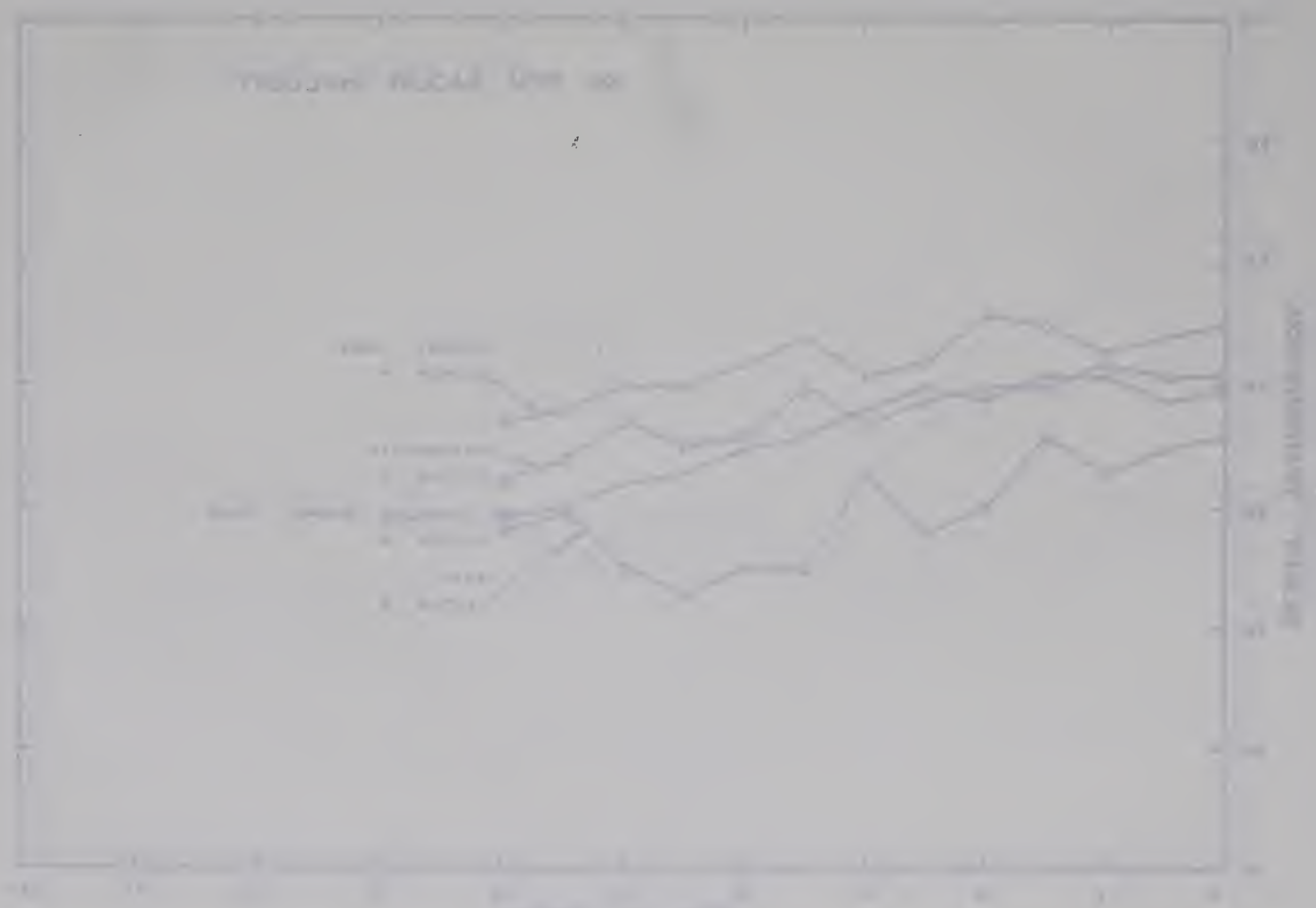
FIGURE 36. 5.0 U.S. GPM PER SQ. FT.

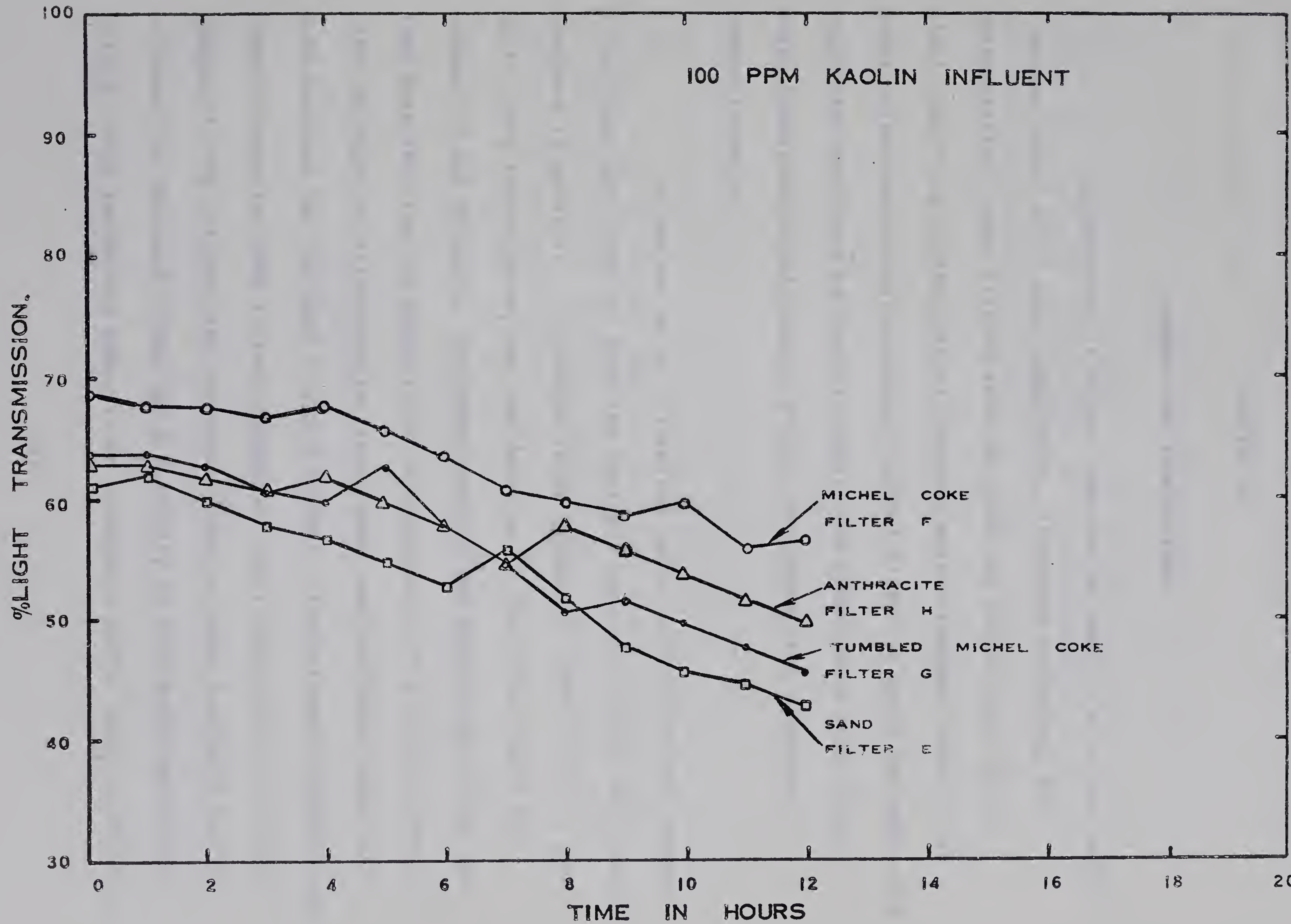




RUN 16 E 16 F 16 G AND 16 H. EFFLUENT TURBIDITY CURVES

FIGURE 37. 2.0 U.S. GPM PER SQ. FT.



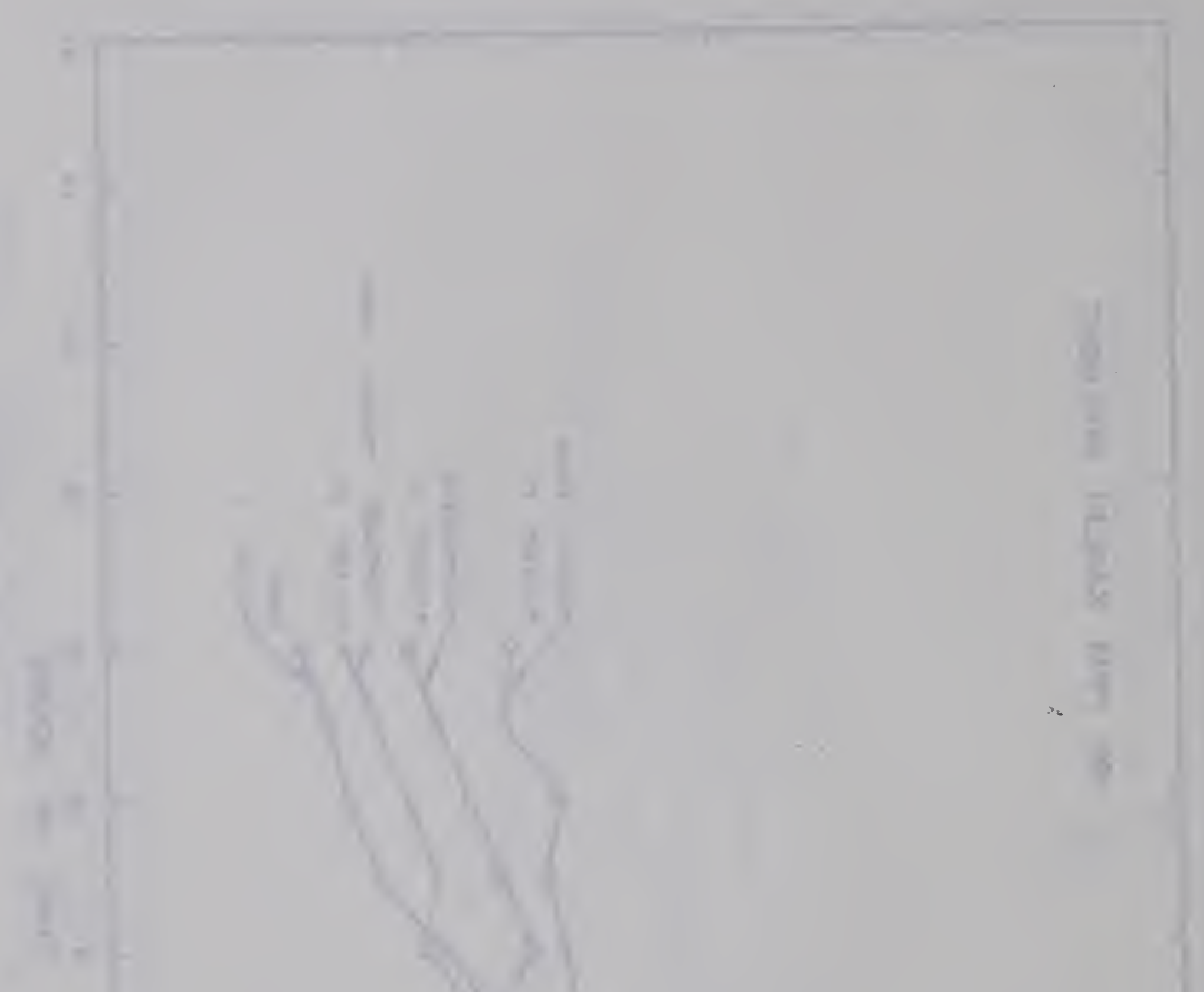


RUN 17 E, 17 F, 17 G AND 17 H.

FIGURE 38

EFFLUENT TURBIDITY CURVES

4.0 U.S. GPM PER SQ. FT.



CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 To determine if Michel coke can be used in an actual water treatment plant which uses coagulation, lime-soda softening, and sedimentation, model filters were designed and tested under actual plant conditions at the City of Edmonton water treatment plant. Two model filters were used, one was a control filter in which the media was the filter sand used at the City plant, the other was a test filter which contained Michel coke or Michel coke above fine sand as a composite media.

5.2 In one series of filtration tests the conventional graded filter beds were used for both the test and control filters, which were operated in parallel. Filtration rates between 2.4 and 12.0 U.S. gpm/sq.ft. were investigated, and the duration of the filter tests was between 12 and 30 hours. The head loss for the Michel coke filter was less than that for the sand filter in each case. At 2.4 U.S. gpm/sq.ft., after 30 hours of filtration the total head loss for Michel coke was 2.06 feet and for the sand it was 3.39 feet. The effluent turbidity was close to zero for both filters throughout the filter test. At 5.0 U.S. gpm/sq.ft. the effluent for the Michel coke had zero turbidity but the effluent for the sand filter had a turbidity of 0.25 parts per million (SiO_2). Thus the Michel coke filter produced a better quality effluent

than the sand and the same time sustained less head loss. The smaller head loss for coke can be explained by the fact that it has a higher porosity than the sand.

5.3 The specific surface area of Michel coke is 24.3 square meters per gram and that of sand is 0.6 sq. meters per gm.. It is likely that the larger surface area of the coke enables it to remove turbidity more effectively than filter sand.

5.4 The tumbled coke has a porosity of 58% and the rough Michel coke had a porosity of 66%. The specific surface area of the tumbled coke is also less than that of the rough coke. Tumbling the coke in the ball mills had the effect of removing the jagged surface of the grains, thereby reducing the porosity and the specific surface area. These tests show that the rough coke produced a better quality effluent than the tumbled coke. It is likely that the roughness of the coke grains is an important characterisitc which enables it to remove turbidity effectively.

5.5 A composite media of coarse Michel coke above a layer of fine sand was also investigated. Two composite beds of different grain sizes were tested in parallel with the conventional sand filter at various rates of filtration. The head loss and rate of increase of head loss were less for the composite beds than for the sand filter. The composite beds also produced a better quality effluent than the sand. There was no mixing of the Michel coke and the sand at the interface during the backwashing process.

5.6 The filtration process was normal for the Michel coke filter, the turbidity was removed by the upper layers, and moved progressively down through the media during the filter run. No caking occurred and the coke expanded easily when it was backwashed. The turbidity was readily washed from the coke grains. There was no discoloration of the grains, and they did not become encrusted with carbonates during the test program. It is felt that Michel coke is a suitable media for use in municipal filters.

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